REPORT
ON
LOW COST HOUSING

The Report of the Comfort Survey Committee,
appointed by the Government of India to study
the design and performance of the houses put up
for the International Exhibition on Low Cost
Housing, in New Delhi in 1954. The
report also embodies the principles
which govern the design of low
cost houses in hot region as
recommended by the
Committee

NATIONAL BUILDINGS ORGANISATION
MINISTRY OF WORKS, HOUSING & SUPPLY
GOVERNMENT OF INDIA, NEW DELHI

THE COMFORT SURVEY COMMITTEE

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Lt. General H. Williams, Director, Central Building Research Institute.

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Chief Engineer, Central Public Works Department.
Engineer-in-Chief, Army Headquarters.
Director, Civil Engineering, Railway Board.
Director, National Buildings Organisation.
President, Forest Research Institute.
Housing Adviser, Ministry of Works, Housing and Supply.

THE TECHNICAL COMMITTEE

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Sardar Sarup Singh, Director, National Buildings Organization.

Members

Engineer-in-Chief, Army Headquarters.
Chief Engineer, Central Public Works Department.
Director, Civil Engineering, Railway Board.
Housing Adviser, Ministry of Works, Housing & Supply.

Secretary

Shri K. Rama Varman, Joint Director
National Buildings Organisation.

Letter of Transmittal

COMFORT SURVEY COMMITTEE
ON
LOW COST HOUSES

No. CSC. *New Delhi, the 22nd January,* 1957.

To

The Secretary,
Ministry of Works, Housing and Supply,
New Delhi.

Sir,

The Comfort Survey Committee was formed by you in August, 1954 for formulating recommendations and preparing a report on the experience gained as a result of the International Housing Exhibition held in New Delhi in January, 1954.

We are enclosing our Report in two parts. Part A deals with the general aspects of planning, design, choice of materials and specifications for low cost houses. Part B deals with the experimental studies conducted by the Central Building Research Institute on forty houses put up at New Delhi for the above purpose.

Yours faithfully,

Lt. Gen. H. WILLIAMS
(Chairman).
H. D. AWASTY.
J. M. RIJHWANI.
C. B. PATEL.
H. C. VIJH (for Engineer-in-Chief).
SARDAR SARUP SINGH.
K. L. AGGARWAL.

K. RAMA VARMAN,
(Secretary).

PREFACE

The International Low-Cost Housing Exhibition during 1954 was made the occasion for an invitation to various house designers and builders to design and construct low cost houses (estimated to cost under Rs. 5,000) for hot-arid regions, for hot-humid regions and for rural areas. As a result 73 houses were erected. The particulars of design and costs of these houses have been published by the Ministry of Works, Housing and Supply, Government of India, in the publication entitled "Low Cost House Designs".

Arising out of the exhibition was the suggestion that the different methods in the designs adopted for this exhibition may be studied with a view to evaluate their merits. For this purpose the Government of India, Ministry of Works, Housing and Supply, appointed a Comfort Survey Committee to make a detailed examination of these points.

The Comfort Survey Committee divided the work into two parts. The first part dealt with the layout, architectural standards, space utilization and structural designs. The second part dealt with experimental work on the buildings actually constructed, the experiments covering aspects of thermal peformance, moisture penetration, ventilation, day-lighting, etc. For co-ordinating the work a Technical Committee was nominated.

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The Committee held the view that the criticism of individual designs be avoided as far as possible; but the material made available be utilized in framing recommendations. This report has therefore been divided into two parts. Part 'A' comprises the general results of evaluation of these houses which have been brought out in the form of general principles involved in the design of low cost houses; some general comments on the behaviour of these houses are also included at the end of Part 'A'. Part 'B' consists of research report of the Central Building Institute, Roorkee, and gives details of the tests conducted on these houses with an appreciation of the results obtained.

The recommendations given in Part 'B' are the results of Scientific investigations and are presented as such, and do not carry the endorsement of this Committee. Detailed comments on the research report will be gratefully received by the Director, Central Building Research Institute, Roorkee.

Technical data included in this report have been drawn from various sources, which are appreciatively acknowledged.

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PART A

Principles of Designs of Low Cost Houses in Hot Regions

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INTRODUCTION

The result of the evaluation of houses constructed for the International Housing Exhibition in 1954, is brought out in this report in the form of a manual for low cost housing incorporating the general principles involved in the layout, design, selection of materials, specifications and construction of houses. An attempt has also been made in this report to bring together available known information on various aspects of house design and construction. It is not claimed that they are the last word on the subject. Ideas with regard to emphasis on different objectives in design vary and new techniques continue to develop.

Opinions and comments of experts in the field of engineering and architecture are welcome. Such communications may be addressed to the Director, National Buildings Organisation, 11-A, Janpath, New Delhi.

The main body of the report refers to constructions in urban areas. The problem of house design and construction in rural areas using local resources and materials is so diverse that only broad lines and principles can be laid down in this matter.

Even in urban areas the land values and consequently the density of the housing vary considerably. Cases of areas with high land values necessitating vertical development, tall houses and apartments are precluded from the scope of this report. This report is intended to cover mostly single storeyed and double storeyed houses in semi-urban areas, of detached, semi-detached or terrace construction. The main technical considerations can, however, be applied to multi-storeyed construction as well.

SIZE OF PLOTS

The pressure on land in most urban and semi-urban areas is becoming more and more pronounced with the result that there is a great need for economy in land.

In great metropolitan areas like Bombay, the land values vary from sector to sector. In areas with high land values, the land should be exploited to the maximum extent for economy. This is done by construction of multi-storeyed buildings. The overall density, however, does not exceed the planners' specifications. Building of flats in tall buildings does not necessarily save land in proportion to their height but provides open space and green belts necessary from points of view of health and hygiene.

In most suburban areas in India, single-storeyed construction is still possible and, in any case, building in more than two storeys is not very essential. These low-cost constructions can be detached, semi-detached or in rows. Detached or semi-detached houses offer the advantages of flexibility in planning and layout and possibility of future extension. Row houses on the other hand are cheaper in costs of land and services. Houses constructed in rows of five or six are found to be advantageous in this respect. When the economic status and income of the average tenant is kept in mind, there is little possibility of low-cost houses being added to in the present and foreseeable future. It appears preferable, therefore, to take advantage of the economy that could be effected by row-construction.

Whether the construction should be of single storey or of two or more storeys will depend upon the land value obtaining in the area. High cost of land leads to intensive building and multi-storey buildings are preferred there. Such constructions, however, are possible in areas only as a commercial enterprise or as a co-operative effort in building. In the case of owner-occupied tenements or flats in an apartment building, combined services and spaces will have to be maintained by the community. This sometimes results in a low standard of maintenance and insufficient attention to the tidiness of the open spaces in the estate due to the absence of a sense of ownership and associated individual responsibility in the matter of shared services and conveniences.

The sizes and dimensions of plots are matters for town planners to lay down, but from general considerations a plot size of 32 ft. frontage and 60 ft. depth appears necessary for semi-detached houses with two rooms. In the case of row houses the frontage can be further reduced to 24 ft. width.

The usual type of town-planning in this country is to have a front road and a back lane between two back-to-back rows. The back lane is essentially a service lane. The service lane between two rows of houses in practice deteriorates into garbage dumps as the owners do not have any responsibility for its proper maintenance. Besides increasing the cost of services this places a heavy load on the estate or the municipality. The Committee therefore suggests that the back-lane may be dispensed with altogether in the case of detached and semi-detached houses*. The water and sewer lines may in such cases be taken through the compound of one or the other of the two rows of houses that they serve.

The difficulty with this arrangement is, however, that it necessitates a direct entry from the front to the back of the building without having to go through any living rooms of the houses. In the case of detached or semi-detached houses this presents no difficulty as a side-passage is possible within the plot boundaries. In the case of row houses, however, this will have to be provided in the shape of an entrance lobby and passage. The omission of back lanes in such cases will depend on the design of the houses and comparative economy of the cost of land and services for the back-lanes on the one hand and the cost of extra space required for the passages or lobbies in the house designs on the other have to be carefully considered.

Whichever arrangement is decided upon, it is recommended that individual plots shall be fenced off; as this arrangement encourages the occupants to maintain their plots in a neater and tidier condition.

Cost of roads is a substantial proportion of the development cost of estates. The length of paved roads should, therefore, be reduced to the minimum. Approaches to rows of houses can be provided by lanes taking off the main road. This also reduces the traffic hazard for the children living in the colonies.

Orientation of Buildings

Ordinarily when a house is planned on any site it is usual to consider the climatic features of the area as regards temperature, humidity, rainfall, winds, etc. In the case of detached houses planned with care, the orientation of the buildings in relation to these factors receives due consideration. But in urban areas where the size of plots, layout and the types of construction are governed by the surroundings and by the requirements of town-planning very little scope exists for the best orientation of individual buildings. A knowledge of the main factors that affect comfort inside the house will, therefore, be of use while designing houses under the limitations imposed by town-planning.

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* Shri J. M. Rijhwani held the view that even in the case of detached and semi-detached houses, the back lane has its advantages and its provision therefore should not be ruled out.

India is mostly in the tropical and sub-tropical regions. Except for the uplands the climate is hot or warm, humid or dry. The main principles that govern the indoor comfort in designing for hot climates are—

(i) the indoor wall and surface temperatures should be low enough to permit cooling of the body by radiation.

(ii) the ventilation or air-movement should facilitate evaporation to a degree which will avoid discomfort felt by conscious sweating.

(iii) the air temperature in the room should be as low as possible to enable the human body to lose the heat by convection.

These principles have different applications in the hot-arid and hot-humid regions. In the hot-arid regions, usually the diurnal variation in temperature is fairly high. Direct heat penetration into the wall and roof has to be prevented and controlled by choosing materials with low diffusivity so that the penetration of the heat through the materials is delayed as much as possible. Preferably such buildings should be ventilated freely during night-time to allow the walls to lose the accumulated heat during the cooler period. Otherwise, the cumulative effect of the heat stored during summer days will make the room intolerable during day-time. For night-living the preference in this climate is to sleep in the open. If indoor night-living is required, the rooms designed for night-living should be of light construction which, while it makes the rooms uncomfortable during day will enable their quick cooling after sunset. In ordinary low-cost housing separate provisions for day and night living inside the building are not possible as the indoor space available is too limited.

The heat of radiation absorbed by the roof and walls depends on the angle of incidence of the rays on the respective surfaces and the duration. A flat surface like the roof gets the maximum punishment in this respect. Next in intensity is the heat falling on east and west walls. The north and south walls receive maximum heating effect seasonally. The angle of incidence of the sun's rays on the north and south walls in summer is comparatively greater and hence its co-sine smaller and these walls can, therefore, be protected by chajjahs and other shading devices. It will thus appear that the east and west walls should receive careful shading and protection. In row houses this is possible by building the houses with north or south aspects, the east and west walls of all but the end houses serving as internal walls in the blocks. The unprotected lengths of east and west walls in houses with other orientations should be kept at the minimum and insolation through openings and windows should be avoided by screens.

In the hot-humid regions, the main factor that controls the design for comfort is ventilation. Air movement enables the body to lose heat by evaporative cooling. The orientation of buildings in such climates should, therefore, take advantage of the winds and particularly the low-velocity winds. The window and permanent ventilation in such buildings should be placed low and through ventilation should be ensured.

In orienting buildings in humid tropics, the effect of the monsoon winds or gales and of wind-driven rain should be borne in mind. The rain should be protected against by canopies, chajjahs, verandahs and other means. Even the low velocity winds are critical and these should be admitted by careful positioning of openings.

To design buildings scientifically for comfort, meteorological data and charts can provide a useful tool. The National Buildings Organisation has prepared regional climatic charts for Delhi for this purpose*. Preparation of similar charts for other regions in India is one of the projects which this Organisation has been entrusted with.

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The indoor comfort is a factor of simultaneous values of air-movement, humidity and temperature and there is a need for simultaneous observations of these factors in meteorological observatories. Moreover, there is a need for frequency tabulation for maximum and minimum temperatures in addition to the mean temperatures. The design factors should depend on the higher intensity values and their frequency in the case of temperature, wind and rainfall.

In designing buildings for climate, the needs of heat insulation and ventilation are often conflicting. There should be a definite preference towards allowing for the requirements of ventilation in such cases because protection against sun is often possible by design of suitable roofs and walls, provision of verandahs and by careful grouping of the rooms. Chajjahs and verandahs should be used as shading devices with care. Taking Delhi as an example, chajjahs as shading devices are of no value on the north face and of doubtful value on east and west faces though they are of some use for protection of openings against rain. Verandahs on the north are of use in summer but will be rather cold in winter. In the east too they are of limited value. They are best placed in the west if the evening summer sun is protected by screens like chicks. They are quite unnecessary and often disadvantageous on the south especially in the northern region.

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* Climatic Data for Design of Buildings (Delhi Region).

Under the project sponsored by the Comforts Survey Committee experiments were conducted by the Central Building Research Institute on the houses constructed for the exhibition. The results from experiments have not been conclusive enough to determine quantitatively the effect of orientation on indoor comfort. The houses erected were not planned for these experiments so that the variants in houses of different orientations were too many to admit of any comparisons of data observed. It was, however, noticed that buildings with long walls facing east which would ordinarily have been termed inappropriate from considerations of effects of solar heating have stood high in rating for indoor comfort principally because the roofs and walls had adequate heat capacity and suitable protection was afforded on the East and West against penetration of direct rays of the sun inside the building. This confirms the view that it is possible to protect buildings against solar heating by careful choice of materials and designs and keeping this in view, it is of advantage to plan buildings to secure good ventilation during the humid periods of the year. The detailed report embodying the findings of this investigation will be found in Part B of this report.

Architectural Treatment

It is a truism often repeated that houses are intended to be lived in and not looked at. While there is no doubt that even the low-cost houses should be aesthetically pleasing, their planning should take into account more of their functional requirements and economies. A pleasing elevation should be the aim but without detriment to a rational plan. Unnecessary architectural features that add to the cost should be avoided. For example, in Delhi chhajahs are of some use for protection against sun only on the south face. Protection against the sun in East and West faces can be obtained by shading trees and creepers and the glare of the low westerly sun can be mitigated by shrubberies and hedges. Chajjahs are, however, of some value to protect openings on other faces from beating rain.

Standards of Accommodation and Planning of Space

No specific standards of accommodation for low-cost houses have been laid down nor is it practical to lay them down in the context of prevailing housing shortages and limited resources. In our country the ideas of what we should have should not be mixed up with the realities of what we can have. It has been agreed by most authorities, that wherever possible there should be at least two rooms in a dwelling unit. The present standard of a dwelling unit with a single living room and a cooking verandah has been forced on us by circumstances. Crowded living in one room by an average family of five is undesirable from some hygienic and social considerations. It is, therefore, to be recommended that the minimum requirements for housing should be two rooms with ancillary space. Where economically possible the following standards of accommodation shall be provided:

2 rooms	120 sq. ft. (each)
Kitchen & Store	80 sq. ft.
Verandah	120 sq. ft.
Bath & washing space	24 sq. ft.
W. C.	16 sq. ft.

Where however provision of one-roomed houses is dictated by economic considerations and by the desirability of providing maximum number of dwelling units within the limited finance available a more restricted standard may have to be applied. No living room shall be less than 120 sq. feet. A back verandah of at least 90 sq. ft. is desirable. Where possible a separate cooking space shall be provided besides independent bath and W.C. for each unit. If the houses are facing south or west protection against the summer sun in the shape of a front verandah is desirable. In the single storeyed construction and in the ground-floor houses of two storeyed construction an enclosed courtyard of an area of about 300 sq. ft. is desirable. In the first floor by building over alternate units some open space can be provided for the first floor dweller too.

The verandah serves to keep off the sun in the east, west and south aspects. To a certain extent, it reduces day-lighting in the living rooms that it protects but this is not a serious consideration in tropical countries. Apart from these structural functions, the verandah is almost a social necessity in our country specially in small houses with few rooms of limited size. It is useful in the evenings for sitting out and is used for sleeping at night in warm weather and as dining space when the kitchen itself is not used for this purpose. Where verandah is used for dining purposes the location of the door and the flow of movements shall be such as not to disturb the table arrangements. The functional aspect of the verandah to provide a comfortable space for sitting out and sleeping should not be lost sight of. The verandah should therefore be of adequate size with a feeling of openness which is spoilt to some extent by enclosing it with heavy or solid panelling. The minimum width of verandah (where it is not merely used as a passage) may be 7′ 6″ to 8′. Below this width the verandah is not useful as anything more than a simple passage or protection against weather.

Entry from front to rear in houses should be provided in such a way as to cause minimum disturbance to the utility and privacy of the living rooms. Sometimes to provide minimum frontage two rooms are grouped one behind the other with the result that both the rooms are to be crossed through to reach the rear. This leads to great wastage of space and reduces the utility and privacy of the rooms.

A single room in front with entry to other rooms like kitchen and bed rooms through it has the advantage of good control and may sometimes be necessary when the utility of the room has to be sacrificed in favour of reduction in cost. A subsidiary or service entry facilitating free circulation and independent utilisation of space in all rooms can be obtained by providing a small lobby, both rooms and entry to the rear verandah being thus made available independently at the same time maintaining adequate privacy.

Lengthy corridors should be avoided in planning. If at all a corridor is necessary it is better to provide a straight one. "L" shaped and irregular corridors cause confusion and lead to the wastage of space. Sometimes it may be essential to conserve space to utilise part of one of the rooms as the passage by placing two doors opposite one another, but to provide such an arrangement for both adjoining rooms would mean wastage of space and this may be avoided.

Any room with internal acute angle and trapizoidal shape causes waste of space and should be avoided. Rectangular rooms are preferable. The size of the rooms should depend upon the function of the room, and the furniture to be used, adequate provision being made for space to move around. Further the usable space in the room mostly depends upon the positioning of the doors. A generally adopted size of a room of 120 sq. feet area is 12′×10′. Such a room is definitely less advantageous than a room of 13′-6″×9′ for use as a bed room though the area in both cases is practically the same. Width of bed rooms should preferably be kept at a minimum of 9 ft. providing space for the cot (length ranges up to 6′-6″) and movement. The size of the kitchen will depend upon the use to which it is actually put. If the kitchen is used only for cooking and separate dining space is provided in the back verandah or elsewhere an area of 54 sq. ft. for the kitchen is sufficient. If the kitchen is used for dining as well, a minimum area of 80 sq. ft. is recommended. Careful grouping and positioning of shelves and doors may not only improve available space but also add to the working comfort of the housewife. Thus the provision of a corner fire-place and a corner sink in a narrow kitchen of say 6' width leaves little room for the housewife. Similarly the provision of a deep cupboard in a narrow kitchen placed directly opposite the fire-place causes overcrowding and congestion in the internal arrangements of the kitchen. Long and narrow kitchen is not very suitable as the housewife who cooks sitting prefers to have everything within her reach without having to move about too much.

It is necessary in low-cost houses to provide bath and W.C. with independent approach. A longish bath room is better in shape and utility. Bath needs a larger area for washing on the floor and for keeping the tub etc. whereas a W.C. requires only about 3 ft. width. A width of more than 3 ft. is a waste in the W.C. It is, therefore, uneconomical to provide the same widths for the W.C. and the bath room. Simple amenities like niches or brackets to hold soap boxes and pegs for hanging clothes in bath rooms increase their utility but are often lost sight of by the designer.

Ample shelving arrangement and storage space shall be provided in the kitchen or in an independent adjoining store. Open shelving of at least 30 sq. ft. is desirable. A cup board preferably with fly proof jali door 2'6"×6'0"×1'4" deep with four layers of shelves will be a very useful amenity in the kitchen. In the living rooms a full cupboard in one of the internal partition walls with shutters openings in the moving space is an ideal arrangement. A projected cup-board in a room leads to waste of space and the shape of the room is also sometimes spoilt. Cup-boards should always be provided near moving spaces so that a double advantage in circulation is derived therefrom. A cup-board provided in a wall in the sitting corner in a living room affects the furniture layout adversely. Positioning of cup-boards should therefore be decided after studying the furniture layout. A suitable size for cup-boards is 2'-6"×6'-0"× 1'-10". Where it is desired to provide cup-boards only in one of the rooms open shelves may be provided in the other room. The depth of such shelves need be only 10".

At least one window is necessary in each of the rooms for view and ventilation. Positioning of two doors in a corner of the room affects the utility of the room when both the doors are opened and may create bottleneck in circulation. Front and rear doors are not necessary in two adjacent rooms. It will be more economical to provide inter-communication between the rooms avoiding at least one front door in the second room.

In buildings with limited space constructed in hot climates an enclosed courtyard is a great boon and almost a necessity. In the case of single-storeyed buildings, these can easily be provided. A minimum depth of 15 ft. for the full width of the plot is recommended.

FOUNDATION

The heaviest loading likely to come on the bases of footings for typical brick dwelling on nearly level sites are as follows:—

1. Single storeyed brick structures with concrete roof.

   (a) 9″ external wall 2,000 lbs./lenial foot.

   (b) 9″ internal wall 2,700 lbs./lenial foot.

2. Double storeyed brick structures with R.C.C. middle floor and roof.

   (a) External walls—9″ in both floors—3,500 lbs. per lenial foot.

   (b) External wall—13½″ ground floor and 9″ in first floor—4,000 lbs. per lenial foot.

   (c) Internal wall—9″ in both floors—4,200 lbs. per lenial foot.

For purposes of calculation of stresses an eccentricity of 2″ in external walls and 1″ in the internal walls may be assumed in loading.

Foundations are usually built on—(1) rock, (2) sand and gravel* and (3) plastic soils**.

Rock suffers negligible deformation under normal loads from light buildings. As the loading imposed on continuous footings of domestic and other light buildings will rarely approach the bearing value for any rock, brick and masonry walls may be built directly on rock foundation with a levelling course of 6″ concrete which may be 6″ wider than the width of the load-bearing wall. The concrete should not be less than 6″ thick at any point if the rocky base of the trench is sloping.

The usual type of failure occurring in an overloaded compact sand or gravel foundation is known as general shear failure. The most important property to be considered in designing footings on compact sand and gravel is the resistance of the material to this type of failure. This resistance increases rapidly with the depth of the footing. The resistance to sliding or shear is greater in damp sand than in dry sand, but when actually submerged the sands and gravels are less resistant to shear forces than when they are dry. Most sands and gravels have approximately similar frictional properties so that the bearing capacity for dry compacted material can be approximately predicted. It is, however, difficult to give a general figure for the bearing capacity of sand or gravelly soils because this depends on the shape of the footing, the depth of the footing and the eccentricity of the loading. *Table* 1 gives the loading recommended by the Australian Commonwealth Building Station for central loading on dry compact materials. As these may not apply to all Indian non-cohesive soils these figures may be taken only as a guide in the absence of similar figures for our soils. It will be noted that the wider the footing the greater the bearing capacity and also the bearing capacity increases with depth. Similar tables for Indian soils will simplify practical calculations on bearing capacity. The eccentricity reductions that are to be taken into account are given in *Table* 2. If the ground water is met with at a depth below the footing which is less than its width the bearing capacity is considerably reduced and is halved for purposes of design. Similarly less compact sand or gravel gives correspondingly lower bearing power. In case of doubt it is preferable to carry out a loading test for all important structures.

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* Under commonly accepted definitions hard gritty material above 0·08 inch diameter is classified as gravel while similar material from 0·08 inch to 0·008 inch diameter is classified as sand. Gravel and sand may occur mixed together or mixed with finer material. Gravels and sands have no cohesion.

** Soils in which more than about 1/10th of all particles is below ·008 inch are regarded as plastic soils. Their behaviour differs considerably from that of sand and gravel and the difference becomes more marked as the sizes of the smaller particles diminish. Silts and clays are such plastic soils. Another method of defining such soils is to describe them as composed of particles invisible to the naked eye and exhibiting low to high plasticity.

Plastic soils are subject to slow movement such as shrinkage swelling or consolidation not necessarily connected with changes in foundation loading. The plastic soils increase in volume with increase in moisture content and decrease in volume with decrease in moisture content. They may consolidate if subjected to compressive loading and may expand on release of such loading. In the case of such soils the time required for loading consolidation to take place in footings of domestic buildings and similar small footings is short.

The footing failure in plastic soils may occur in one or more of the following ways.

(a) successive expansion or contraction of the soil due to changes in moisture content.

(b) settlement of foundations due to excessive consolidation *i.e.*, the excessive contraction of the soil under compression caused by the load.

(c) general shear failure in which the soil is pushed down below the footing to bulge upward alongside.

Expansion of a soft soil may cause a general shear failure. In this case a subsequent decrease of moisture will cause the footing to subside.

TABLE 1

ALLOWABLE LOADING ON COMPACT SAND OR GRAVEL FOUNDATION

Loadings are per ft. run for strip footings, and total load for other footings.

Depth of bottom[2] and type of footing	Allowable loadings for various widths of footings, of central loading in lb.[1]							
	1′ 0″	1′ 3″	1′ 6″	1′ 9′	2′ 0″	2′ 6″	3′ 0″	3′ 6″
6″								
strip . . .	500	800	1200	1600	2100	3400	4900	6600
square . . .	400	800	1400	2300	3400	6700	11800	18500
circular . . .	200	500	900	1400	2000	4000	7000	10800
8″								
strip . . .	800	1200	1600	2100	2700	4100	5700	7600
square . . .	700	1300	2100	3200	4600	8500	14300	21900
circular . . .	500	800	1400	2100	2900	5400	9000	13500
1′ 0″								
strip . . .	1400	1900	2500	3100	3800	5500	7400	9600
square . . .	1300	2200	3400	4900	6800	12000	19300	28800
circular . . .	900	1500	2400	3400	4600	8100	12900	19000
1′ 6″								
strip . . .		2600	3300	4100	5000	6900	9100	11500
square . . .		3000	4600	6700	9000	15500	24400	35600
circular . . .		2200	3400	4800	6400	10900	16900	24400
2′ 0″								
strip . . .			4200	5100	6100	8300	10800	13500
square . . .			5000	8400	11300	19000	29400	42500
circular			4400	6100	8200	13600	20800	29800
2′ 6″								
strip . . .					7200	9700	12400	15400
square . . .					13500	22500	34500	49300
circular . . .					9900	16400	24800	35200

Note:(1) These loadings are worked out on the following assumptions :

Angle of internal friction	30°
Unit weight of the soil	90 lbs. per cu. ft.
Factor of safety	1·67

(2) Depth of bottom may be reckoned from 9″ below the ground surface.

TABLE 2

ECCENTRICITY REDUCTIONS

Eccentricity divided by width of footing $=\frac{e}{d}$	Ratio of Reduction of average safe bearing or loading value	
	For strip, square, or rectangular footings	For circular footings
0·05	0·9	0·85
0·10	0·8	0·7
0·15	0·7	0·55
0·20	0·6	0·4
0·25	0·5	..

Note : If eccentricity occurs in two directions both eccentricities must be added together before entering the table.

Properly designed footings on plastic soils may be:—

(a) below the region of seasonal moisture change.

(b) within or near the top of the region of seasonal moisture change but sufficiently strong or sufficiently stiff either in themselves or with the structure to cause the building to rise and fall evenly over its full extent.

(c) within the region of seasonal moisture change but founded on a soil whose volumetric changes are sufficiently light not to over-stress or crack the super-structure.

(d) within the lower part of the region of seasonal moisture change but so heavily loaded that when the soil is flooded by rain, harmful expansion of the soil is suppressed.

Some suggested safe bearing values in tons/sq. ft. for plastic soils* are given below:—

Hard or stiff clay	4—5
Clay (moderately dry)	2—3
Clay and Sand-clay (moist) . . .	1—1½
Clay and silt (soft)	½—1

The Indian Standards Institution is drawing up Code of Practice which will include allowable loads on foundations for various Indian soils. The Code will also include methods of testing foundation in the field and in the laboratory and interpretation of the test results.

The Commonwealth Experimental Building Station, Australia, has given certain tentative values for bearing capacity for normal plastic soils occurring in Australia for small footings of buildings.** From experience gained and from theoretical considerations it has been recommended by them that values greater than the commonly accepted bearing capacities can be adopted in the case of design of small footings. Table 3 gives an indication of the relationship between the commonly accepted bearing pressures for the soil and the permissible pressures in the case of small footings. (Table 2 gives eccentricity reductions recommended). These figures have been recommended on the basis of tests made on Australian soils. In the absence of similar tables for Indian cohesive soils these factors may be used for our conditions judiciously.

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* The various clays may be roughly distinguished as follows :—

Clay : A fine grained inorganic soil possessing sufficient cohesion when dry to form hard lumps which cannot be readily pulverised by fingers.

Moist clay and clay sand mixture : A clay sample when freshly taken can be indented only with strong thumb pressure.

Soft clay : A clay which when freshly sampled can be moulded under relatively slight pressure of the fingers.

** Footings and Foundations (I & II), Commonwealth Experimental Building Station.

TABLE 3

TENTATIVE VALUES FOR BEARING CAPACITY PRESUMED FOR AUSTRALIAN PLASTIC SOILS

(Intermediate values may be interpolated)

Commonly accepted bearing capacity for large footings	Round for Square Footings			Strip Footings		
	1 ft. wide	2 ft. wide	3 ft. wide and over	1 ft. wide	2 ft. wide	3 ft. wide and over
Tons/sq. ft.	All values in tons per square foot					
1·00	1.87	1·52	1.33	1.40	1.14	1.00
2·00	3·47	2·94	2·67	2·60	2·21	2·00
3·00	5·07	4·37	4·00	3·80	3·28	3·00
4·00	6·67	5·80	5·33	5·00	4·35	4·00

Note : It will be seen that the allowable load intensity in such soils is about 20% greater for square and circular footings than for strip footings.

In certain situations it may be necessary to have footings of the pier and beam type. This is the case where the top soil is very poor and reasonably good foundation is available at a depth of 5 to 10 ft. In such cases the main load is transmitted to the lower layer through bored-piles or columns. These are spanned above the ground level by beams on which the super-structure rests. The design of the plinth beams in such cases is worked out by assuming a maximum bending movement of WL/100 in case of a solid wall or walls with openings in the centre and WL/50 for a wall with opening towards the ends. 'W' is the weight of the wall and the load transmitted thereto by the roof and live loads and 'L' is the effective span of the beam between two piers or piles. Such type of construction is specially suitable in certain black cotton soils, the depth of the column or pile depending upon the depth at which—(a) the black cotton soil ends or (b) the seasonal changes due to moisture variations in the soil are small enough not to affect the base of the footings.

Design of foundation in black cotton soil is still in the experimental stage in this country. Researches done so far in Australia, Africa, U.S.A. and in this country have indicated the following general principles for design:

(a) Pier and beam construction has been recommended as an effective method. The enlargement of the bottom of the pier to provide greater bearing area and to increase resistance to uplift is a sound technique. This system is called the under-reamed pile foundation.

The depth of the pier depends on the zone of constant moisture condition. Some buildings designed on these principles have recently been constructed under the advice of the Central Builing Research Institute, Roorkee and are under observation.

(b) The pile and beam construction is a variation of the under-reamed piled foundation. In this case the piles are ordinary piles either cast in situ or precast and anchored in the soil which is substantially stable against moisture movements.

(c) A less satisfactory but common type of foundation is the strip foundation; these may be either of the deep beam type or inverted tee beam type. This type of foundation does not tolerate any movement and hence should be located in zone of constant moisture content. Where this is not possible buildings tolerating such movements should be constructed which may be of flexible or rigid type. Flexible constructions are usually dry wall constructions with interlocking arrangement between wall units to ensure stability. Steel or wood framing for superstructure may be used with advantage. In rigid construction both the masonry and the crack-control bands of concrete will require heavy reinforcements.

(d) It has been held that in the case of expansive clays, high foundation pressures should be used to counter the effects of the swelling pressure of clays—such swelling pressure has been stated to be over 1½ tons per sq. ft. The pier and beam type of construction is eminently suited for this purpose; but this has to be used with caution lest the bearing capacity of the soil in its wet state is exceeded.

(e) Trees, grass, and vegetation near the building also affect the drying up of the soil resulting in shrinkage. Movement of moisture due to the thermo-osmotic pressures, caused by the differential temperature of the soil under the building and in its surroundings has also been

TABLE 4

MORTARS FOR FOUNDATION CONCRETE

Serial No.	Situation	Type of mortar (all proportions by volume)	*Class of lime	Remarks
1.	Dry sub-grade with sub-soil water-level never within 8′ 0″ of the foundation level.	(*i*) 1 lime, 2 sand. (*ii*) 1 lime, 1 Surkhi and 1 sand. (*iii*) 1 lime, 2 surkhi. (*iv*) 1 cement, 3 lime and 12 sand.	(*i*) A. (*ii*) B, C or A. (*iii*) B or C or A. (*iv*) B or C.	Normally suitable for buildings not more than three storeys high. The quantity of mortar to be used will depend on the grading of aggregate.
2.	Moist sub-grade with high sub-soil water usually 8′ 0″ of less below foundation level.	1:4 or 1:3 (cement sand mortar)		The corresponding concrete mix will be 1:4:8 or 1:3:6

*I.S.I. Classification of lime—

Hydraulic lime..........Class A.
Semi-Hydraulic lime......Class B.
Non-Hydraulic lime....Class C.

TABLE 5

MORTARS FOR MACHINERY IN FOUNDATION AND PLINTH

Serial No.	Loading Condition		Moist sub-grade with sub-soil water less than 8′0″ below foundation level with high percentage of soluble sulphates	Moist sub-grade as in (2) with little or no soluble sulphates	Dry sub-grade with sub-soil water never within 8 ft. of foundation level	Class of lime
1	2		3	4	5	6
1	Heavy and medium loading (4 tons per sq. ft. and above)	Below ground level	1 cement, 3 sand (Use of high alumina cement and pozzolanic cement is recommended.)	1 cement, 1 lime, 6 sand.	1 cement, 1 lime, 6 sand	B or C.
		In plinth	1 cement, 3 sand	1 cement, 1 lime, 6 sand.	1 cement, 1 lime, 6 sand	B or C.
2	Light loading (less than 4 tons per sq. ft.)	Below ground level	1 cement, 3 sand (high alumina cement and pozzolanic cement is preferred).	1 cement, 1 lime, 6 sand.	(*i*) 1 lime, 2 sand (*ii*) 1 lime, 1 surkhi, 1 sand. (*iii*) 1 lime, 2 surkhi. (*iv*) 1 cement, 3 lime, 12 sand.	A B, C or A. B, C or A. B or C.
		In plinth	1 cement, 1 lime, 6 sand.	1 cement, 1 lime, 6 sand.	All specifications as given in the case of masonry below ground level.	As above.

NOTE :—*All loads given in this statement have reference to a slenderness ratio of unity.*

observed and this is often responsible for heaving or settlements of structures.

Much experimentation still remains to be done to evolve an economical foundation for building on such soils.

Appendix I gives a list of the specifications that have been used in foundation concrete and masonry for the traditional constructions adopted in the low cost buildings put up for the exhibition. The width of foundation varied from 1′ 9″ to 2′ 6″. From a perusal of considerations discussed above it will be seen that taking into account the load on foundation and the bearing capacity of the soil an economical width of foundation on ordinary Delhi soil is nearer 1′ 9″ than 2′ 6″ for the type of single storeyed structures that have been constructed. The thickness of foundation concrete should ordinarily be not less than 6″ but it is preferable to have an additional 3″ rammed hard core under the layer of concrete. The coarse aggregate used for concrete may be gravel broken stone or broken brick. In the case of broken bricks, the quantity of soluble salts should not exceed 2 per cent by weight. In most areas lime concrete can be used for foundations, the quantity of mortar and specification depending upon the nature of the sub-soil. *Table* 4 gives the specifications for foundation concrete suitable for ordinary structures. *Table* 5 gives the specifications for mortars for foundation masonry. Certain authorities have recommended that special measures are required in the case of concretes laid in sulphate bearing clays where the ground water contains more than 30 parts of SO_3 per hundred thousand parts or where the clay contains 0·2 to 0·5 per cent of SO_3 in oven-dry condition. In such cases dense concrete should be used and preferably special cement like pozzolanic cement or high alumina cements or super sulphate cements should be used. A mix of 1: 2: 4 concrete is usually recommended in such situations. Action of sulphates in the soil can also be guarded against to a large extent by coating the exposed parts of concrete and masonry with bitumen.

From the bottom-most footing of the foundation masonry the width of the wall should be rapidly reduced to the width at plinth level, the successive footings need be only one course deep till the required thickness of wall is reached. The offsets should not be more than 2¼″ in the case of brickwork and ½ the depth of course in the case of stone masonry.

Careful design of foundations can result in considerable savings in the building costs and is worthwhile.

Dam Proof Courses

The function of the damp proof course is to prevent or reduce as necessary the passage of moisture from parts of walls or floors that cannot be kept dry to parts that must be kept dry. In ordinary buildings the damp proof course is usually provided in our country at plinth levels of walls.

The damp proof course at plinth level has to resist upward movement of moisture. It has been opined that two course of dense bricks (water absorption of bricks on 24 hrs. immersion in water followed by 5 hrs. in boiling water not to exceed 4·5 per cent of its weight) laid in cement and sand mortar (1:3) will resist the rise of moisture by capillary action and that it is of advantage to leave the vertical joints unfilled. Other materials that have been recommended are good slates laid in cement mortar in two courses and flexible materials like metal and bitumen sheeting and semi-rigid materials like mastic asphalt.

Except in places of high water table damp-proofing merely from the point of view of dampness in walls is of comparatively less significance in the hot countries because the dampness caused rarely persists it being evaporated in most areas in a matter of few hours of bright sunshine. The problem, however, takes a serious shape when dampness is combined with the presence of soluble salts in the bricks or in the sub-soil water. In such cases the soluble salts work up to the surface of the walls in upper structure leading to unsightly efflorescence, crystallisation and disintegration of mortar or plaster. This is now observed in many of the constructions in Delhi where the effect of lack of a suitable damp proof course is making itself evident. The damp proof course need not be provided for all buildings in all areas as a matter of course. In rocky areas and in dry areas with low sub-soil water and good drainage no damp proof course may be necessary. While an examination of the old buildings in the areas where damp proof courses have not been provided in the past may be a useful guide in determining whether a damp proof course is required or not for new constructions in the area, some caution is necessary in this matter because the sub-soil water in urban areas often rises after some years due to intensive building in the area resulting in blocked drainage and sometimes to other causes.

Usually buildings constructed with stone masonry in foundation and plinth do not require damp proof courses if the stone used are dense and the mortar relatively impermeable.. The cement-lime mortar 1:1:6 may be considered as sufficiently by impermeable for this purpose but its impermeability can further be increased by addition of fine stone dust or fine pozzolana and by proprietary additives available in the market. Such impermeable mortars may be necessary only for a depth of 18″ below the plinth level to offset the effect of rise of damp resulting from capillary action through the mortars in the masonry.

It has been usual in this country to provide damp proof courses of rich cement concrete or of rich cement mortar, sometimes with the addition of integral water-proofers. The cement concrete is not a satisfactory material to resist penetration of water or water vapour in all conditions and indeed it has a natural tendency to absorb water by capilliarity. For complete protection against moisture, therefore, one of the many alternative specifications referred to earlier may have to be adopted.

To supplement the layer of cement concrete or cement mortar provided as damp proof course it may be adequate in most cases to provide a coating of 1/8th to 1/4th inch thick bitumen or pitch. This requires about 5 to 10 gallons of bitumen or pitch, per one hundred square feet. Thinner films are said to be useless because they are likely to be pin-hold or to become punched during the subsequent placing of the masonry. Suitable materials are bitumens with softening point 50 to 55° C or coal-tar pitch with softening point 35° C to 44°C, heated to a fluid consistency suitable for pouring and spread by brush or skueegee. Fuming should be avoided and a temperature of 180°C should not be exceeded in the case of pitch. The final appearance should be shining and the texture of the concrete should be obscured.

Where the sub-soil contains large quantities of soluble salts and where sub-soil water level is high the cement mortar or concrete layer may be in high alumina or other sulphate-resisting cement. The concentrations of soluble sulphates which may be considered as excessive justifying the use of special cements have been stipulated elsewhere in the report.

Termite Proofing

Through termite-proofing is of comparatively less importance in brick and concrete constructions, it may be necessary to make provision for protection against termites under certain circumstances. This is usually done by the use of termite shields and caps. Other methods used are treatment of the back filling with creosote or with soil poisons.

Some of the methods recommended for prevention of termite attack in buildings are set out below.

1. While clearing the site and back filling trenches all pieces of wood should be removed. Efficient drainage of the site should be ensured as moisture attracts termites.

2. In the case of brick buildings in termite-infested areas termite shields and caps of non-corrosive metal may be laid over the plinths of walls. The edges of these shields may be bent down at an angle

45°. At junctions shields should be welded or soldered together and should not be lapp or butt. The mortars used below the damp proof courses should not be leaner than 1 part of cement, 1 part of lime and 6 parts of sand because termite can penetrate lime mortars or mortars of poor quality. This is specially important where cavity walls have been constructed. In the case of concrete floors, the floor should be at least 3″ thick and shall project at least 3″ into the walls. Junctions of all joints in the concrete floors should be treated with creosote oil at the rate of about one gallon of solution to 100 linear ft. of joints. A five per cent solution of pentrachlophenol in fuel oil or a twenty per cent solution of copper naphthanate may be used in place of creosote oil.

3. All timber should be set after the flooring has been placed and no member should extend through the concrete floor. The timber is thus isolated from the soil. Should it be necessary to pierce the slabs with timber, creosote should be liberally applied all round the base of the timber and the area kept clear so that the termite attack is visible.

4. An additional measure is to dig trenches to a depth of about 18″ around the building and to back-fill the trenches with successive 6″ layers of soil and soil-creosote. The creosote should be used at the rate of one gallon for 5 cubic ft. of soil. To prevent entry of termites through cracks in floor it has been found successful in certain areas to provide a layer of clean dry sand of a minimum thickness of 9″ below the flooring.

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5. In the case of timber-framed buildings the whole super-structure of the building should rest on metal termite caps placed on top of stumps or piers. A minimum clearance of 18″ is desirable below the floor. The space below the floor should be ventilated. The stumps may be of termite resistant timber, concrete or brickwork. All portions of fire place, steps or terraces which join the wood-work above the level of the termite shields should be carefully fitted with shields. Wooden steps should be either isolated from the main building or protected.

Superficial coating of creosote oil or other preservation applied to joists and beams by brushing or dipping is not a permanent prevention against termite attack.

6. If the building is in an area of high termite-hazard at least three to four inspections per year are essential to ensure that the termites have not built galleries to attack the wood-work. In areas of lower hazard at least one inspection should be made in the year.

Superstructure

Superstructure is being dealt with separately under external load-bearing walls, internal load-bearing walls and internal non-load bearing walls.

The specifications usually used for super-structure in traditional construction for load bearing external walls may be divided into the following classes.

(a) earth or stabilized earth walls.

(b) burnt bricks in mud, cement or lime mortar of varying thickness.

(c) natural stone in mud cement or lime mortar.

(d) concrete products as solid or hollow blocks or products of light-weight concrete.

All these specifications and some non-traditional specifications have been tried in the buildings put up for the International Exhibition. A schedule of some of the specifications used with their unit costs will be found in *Appendix II.*

The functions of the external wall in a house are—

(a) to support the structure to the extent it is called upon to do;

(b) to prevent or delay the penetration of heat or cold inside the building;

(c) to prevent the penetration of moisture, high winds and dust;

(d) to insulate against external noise; and

(e) to ensure privacy.

From the point of view of structural stability for single storeyed construction a 9″ brick wall in mud, lime or cement mortar is often sufficient. Similarly a 12″ stone wall or a stabilized earth wall of the same thickness will be found satisfactory. Solid concrete or hollow concrete blocks of 8″ thickness are also found to be adequate from these considerations.

The load-bearing capacity of the wall when load is applied centrally or without eccentricity depends upon—

(a) the individual strength of the brick or the unit.

(b) strength of the mortar.

(c) slenderness of the wall.

It has been recognised by all authorities that the strength of masonry is much less than the strength of the individual unit. The British Standard Code of Practice C.P. 111 (1948) on "load bearing

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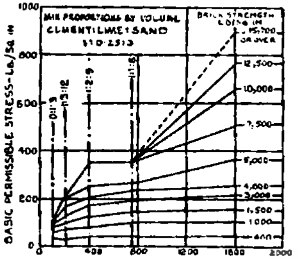
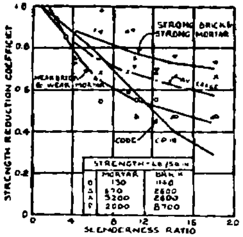
Walls" have recommended the loadings to be taken of bricks or structural units of different strengths when used in association with different types of mortars. A graphical interpretation of these recommendations correlating the strengths of the mortars and of brick or unit on permissible stresses in the masonry according to this Code may be seen in *Charts Nos.* 1 and 2, *Plate No.* 1. The loadings recommended are for central loads and for slenderness ratio equal to unity. The effect of slenderness ratio on the strength of brick-work as given in the above Code is illustrated in *Chart No.* 3, *Plate No.* 1. Similarly the effect of eccentricity of load is illustrated in *Chart No.* 4 *Plate No.* 1. These charts have been prepared for British materials and workmanship and can serve only as a guide to us regarding the trends in variation of strengths with each of these factors. The Indian Standards Institution is working on a similar Code of Practice to suit Indian conditions.

From the point of view of heat-penetration in the hot and arid regions with its great diurnal variations in temperature a 9" brick wall is considerably inferior in performance to a 13½" brick wall. The views of the research workers in this connection are that the heat capacity of the structure is of primary importance for day-living accommodation in such climates. A thick and heavy construction ensures that the inside surfaces remain cooler than air temperature during the hot periods of the day. The regular succession, outside of high temperatures by day and comparatively lower temperature by night constitute a periodical temperature variation which gives rise to a corresponding variation in the inner surface. The temperature changes at the inner surface occur later in time (time-lag) and are smaller in amplitude than the changes which produce them. For homogeneous structures both the time-lag and the amplitude depend on several physical properties considered jointly *viz.*, thermal conductivity, diffusivity, specific heat and thickness of the material. Structures with heat-capacity prevent the passage of heat to the inside of the building by absorbing heat locally. High heat-retaining constructions thus aid the storing up of heat absorbed during the day and re-emitting it in a smaller measure to the interior and exterior during the cooler succeeding night. By their large masses and their high temperature conductances such constructions keep inside surface temperatures down close to the air temperature throughout the day but radiate their excess heat to the occupants during the night. Under such circumstances the factors of interest in the design of walls are the velocity and decrement factor of the heat waves propagated through the construction under thermal loads represented by the difference between inside and outside temperatures, the latter fluctuating in more or less sino-soidal form throughout the 24 hour period.



BASIC PERMISSIBLE STRESSES FOR BRICKWORK RECOMMENDED BY CODE CP 111 (1948)

CHART No 1



STRENGTH OF AXIALLY-LOADED PIERS OF VARIOUS SLENDERNESS RATIOS, AS A PROPORTION OF THE STRENGTH OF A PIER OF SLENDERNESS RATIO OF UNITY.

CHART No 3

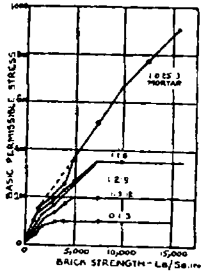
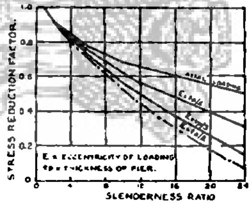


CHART No 2



EFFECT OF ECCENTRICITY OF LOADING ON THE REDUCTION COEFFICIENTS TO BE ASSUMED FOR SLENDER PIERS (CF TABLE 2 OF CODE CP 111)

CHART No 4

STRENGTH OF BRICKWORK

PLATE No 1

Some authorities recommend that the weight of construction providing the heat capacity in such structures should be proportional to the diurnal range of out-door temperatures and suggests that if the diurnal range is 6 to 8 degrees centigrade, there should be 300 k.g. (660 lbs.) of heavy weight materials such as masonry, concrete etc., per cubic meter (35 c. ft.) of the building and for a range of 10 to 12 degrees 600 to 700 k.g. (1,320 to 1,540 lbs.) per cubic meter (35 c. ft.) and over 20 degrees 1,200 k.g. (2,640 lbs.) or more per cubic meter (35 c. ft.); this weight of material should be distributed indoors as lining partition thus presenting a large surface area to the spaces bounded by them.

In the case of structures in hot humid zones, the diurnal range of temperature is comparatively small and the heat capacity is not of much importance. Under such circumstances a 9″ thick wall or less is adequate.

For the buildings tested by the Central Building Research Institute, it was observed that the difference in maximum inside wall temperatures between two constructions one with 9″ external wall and another with 13½″ external wall was of the order of 7 to 10 degrees F in summer. Similarly it was noticed that the capacity of the walls to damp the inner temperature over the external temperature was about 80 per cent. for a 13½″ wall and 70 per cent. for a 9″ wall. These figures can, however, be taken only as indicative because the two walls though alike in point of orientation formed part of two buildings of dis-similar designs. Though improvement in thermal comfort can also be obtained by other improvements in design of roofs etc., it would appear that there is some argument in favour of keeping the un-protected sun-exposed walls of houses in hot arid climates 13½″ thick rather than 9″ from this point of view. The time-lag for the maximum temperature to be attained inside the building after the maximum has attained outside is about 6½ hours for a 9″ wall and about 12 hours for a 13½″ wall from theoretical considerations, though the leakages of hot air and other factors tend to bring make gap smaller in normal occupied houses.

For the same reason that the thermal damping and depression of the maximum temperature on the inside face of the wall depend upon the heat capacity of the construction which is usually proportional to its unit weight, hollow concrete walls have not come off well and were found to be rather poorer in performance compared to a 9″ thick brick wall.

From the point of view of moisture penetration it was observed in the experiments conducted by the Central Building Research Institute that brick-in mud of 9″ thickness shows up very poorly when exposed to wind driven rains. 13½″ wall in mud masonry has come off better. The tests, however, cannot be said to be conclusive as in most cases the junctions of roof and wall were found leaking and this might well have been the cause for the wetness of the walls. Researches conducted in other countries have shown that a 9″ brick wall laid in a plastic mortar of lime or lime-cement and plastered both sides with a similar mortar is proof against moisture penetration. If the rainfall is heavy, however, it is preferable to have a 13½″ wall or a 11″ cavity wall on the exposed side. For single-storeyed construction with sloping roof with eaves projecting a 9″ wall is quite adequate in all cases. Recent experiments conducted by the Central Road Research Institute on behalf of the National Buildings Organisation indicate that a cement-mortar rendering 1:5 made in 1 per cent soap solution affords considerable protection against the penetration of rain in mud walls. Similar specifications can therefore be tried for water proofing 9″ brick wall with external rendering.

In stabilised soil construction the problem is to provide a waterproof non-erodable plaster. Researches on this are understood to be going on currently in the Central Road Research Institute and a report will be published shortly. In rural houses, however, when constant attention is possible from the owner-occupier the traditional plaster made of earth and *bhusa* with *gobri* leeping may be found acceptable.

The concrete-block houses, the shell houses, the *aerocem* houses and cavity walls of the growing house have come off very well in the tests from the point of view of water penetration.

As regards insulation from noise a 9″ wall may be quite adequate as an external wall except in areas where the street noises due to traffic are heavy. The Codes of functional requirements of buildings that are being drawn up by the Indian Standards Institution will give the design requirements for walls from consideration of heat and sound insulation.

A common defect noticed in case of brick walls in buildings is efflorescence. This is due to the presence of soluble salts in bricks or in the soil. By capillary action and drying the salts rise up and get concentrated at the surface. They undergo great volumetric changes while crystallising. This sometimes leads to the disruption of mortar in the brickwork. It is the opinion of experts that bricks containing less than 0·1 per cent. of soluble sulphates (SO_3) are comparatively harmless from this point of view. Other methods to prevent efflorescence are by ensuring that moisture does not penetrate into the masonry by providing damp proof course and by leeching out soluble salts in bricks by prolonged immersion under water which shall be free from salts and frequently renewed. The old specifications in some of the P.W.Ds that the bricks should be kept under water for 7 to 8 hours before being used was perhaps for this purpose. From the point of view of prevention of loss of strength in mortar it should be seen that the bricks are sufficiently soaked and just skin-dry before use. Complete saturation is said to be undesirable and the degree of saturation to be aimed at when bricks do not contain excessive soluble salts is from $\frac{1}{3}$ to $\frac{3}{4}$ of the total water absorption capacity of the bricks.

As stated earlier for any particular strength of brick or masonry unit a corresponding mortar strength gives maximum strength to the brickwork. It is thus apparent that the strength of the masonry is not necessarily increased by indiscriminately increasing the strength of the mortar used. A cement-lime mortar of 1:1:6 proportion used in conjunction with the ordinary bricks available in this country gives all the strength that can be got out of the masonry constructed with these units.

Cement-lime-mortars are preferred to cement mortars for other reasons too; for example they impart resistance of brickwork to cracking and lessens efflorescence on the bricks. Cracks in brickwork are rarely due to directly applied loads; usually they are the result of differential movements between the various parts of the structure caused by foundation settlements or by thermal or shrinkage movement. With a strong mortar, cracks develop between the mortar and the brick and these may pass through the bricks themselves. With a weak mortar, however, the mortar can "give" a little to take up differential movements and so cracking is often avoided. Should such movements be so great that cracking still occurs, this will be distributed throughout brickwork in the joins rather than through the bricks.

Recently additives known as "plasticizers" have been introduced for use in mortars and renderings. By using these additives lime can be eliminated from mortars. These additives entrain small stable air bubbles in the mixes, and these impart plasticity and cohesion to the mix.

Where hydraulic lime is available mortars of one part of lime to two to three of sand by volume are suitable. Where fat lime is available a mixture of 1 lime, 1 ash (or surkhi) and 1 to 2 sand will be suitable for most small building constructions.

Table 6 gives recommendations for mortar that may be used with masonry units for different strength requirements and in different conditions occurring in ordinary building constructions. This statement has been drawn up with special reference to economising in consumption of cement in building constructions.

There have been some apprehensions regarding the use of concrete blocks in masonry. Cracking has been observed and the

TABLE 6

MORTARS FOR MASONRY IN SUPERSTRUCTURE IN UNFRAMED AND FRAMED BUILDINGS

Serial No.	Situation	Special conditions	Type of masonry unit	Type of mortar (Proportions by volume)	Class of lime (A, B or C) ‡
1	2	3	4	5	6
1	Load-bearing walls.	Very heavy loading (8-10 tons per sq. ft.)	Brick of crushing strength of not less than 1500 lbs per sq. in.	1 cement, 1 lime and 6 sand.	B or C.
2	Do.	Arch Work.	Dense bricks. limestone granite etc.	1 cement, 3 sand.	..
3	Do.	Heavy loading (6-8 tons per sq. ft.)	Brick or stone with crushing strength not less than 1000-1500 lbs. per sq. in.	1 cement, 2 lime and 9 sand.	B or C.
4	Do.	Medium loading (4-6 tons per sq. ft.)	Do.	(*i*) 1 lime, 1 to 2 sand, 1 surkhi (*ii*) 1 lime, 1 to 2 sand 1 cinder. (*iii*) 1 lime, 2 to 3 surkhi, (*iv*) 1 lime, 2 to 3 cinder	A, B or C.
				(*v*) 1 lime, 2 to 3 sand.	A
				(*vi*) 1 cement, 2 lime, 9 sand	C
				(**vii*) 1 cement, 3 lime 12 sand.	B
5	Do.	Light Loading (below Brick 4 tons per sq. ft.)		All lime mortars included under No. 4 for "medium loading" can be used.	

(continued)

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* *Tests should be made to determine whether 1:3:12 cement, limes and mortar could give adequate strength for the purpose.*

1	2	3	4	5	6
6	Cavity walls	..	Brick	1 cement, 1 lime and 6 sand.	B. or C.
7	Reinforced brickwork		Do.	** 1 cement, 3 sand with 10% addition of class 'C' lime for better workability.	
8	Half-brick or brick-on-edge parapet walls	..	Do.	1 cement, 1 lime, 6 sand.	B or C.
9	Non-loading bearing partitions.		Light weight concrete, wood wool, slab, hollow blocks.	1 lime, 3 sand.	A or B.

NOTE :—1. All loadings given in this table are for a slenderness ratio of 1·0. Reduction factors as given in Plate 1 Chart 4 are to be applied for slenderness ratios exceeding unity.

2. Lime mortars should be prepared and tested before specifying suitable proportions for important works. The proportions should be so adjusted that after 28 days' curing in moist air it shall have tensile strength of 80 pounds per square inch and a bonding efficiency *i.e.* $\frac{\text{adhesion strength}}{\text{Tensile strength}}$ of 20%

** Addition of lime is approved.

material has been blamed for this. In most cases this cracking is due to *improper curing of the blocks and defects in construction of* the masonry. The Concrete Association of India have brought out a brochure on how to build walls with concrete blocks. If the specifications and the practice recommended in the brochure are followed there will be very little room to complain about the unsuitability of this type of construction as far as cracks are concerned. No structural defect has been noticed in the building constructed according to these specifications in the Low Cost Housing Exhibition.

Cavity walls have not been used to any great extent in this country. These consist of two or more leaves of walls made up of bricks, blocks or precast concrete panels separated by air gap usually 2″ to 3″ wide. The air-cavity provides insulation against heat where air-conditioning is provided. Even in the case of dry hot tropics without air-conditioning the cavity wall does provide some advantage over a solid wall containing the same quantity of materials. Thus a 11″ cavity wall will be superior to a 9″ brick wall. From the point of view of moisture penetration, cavity walls are extremely advantageous. Cavity walls have been constructed for some buildings in the low cost housing exhibition with bricks and with cinder blocks and in both cases the performance of walls from the point of view of moisture penetration was excellent. In the case of a 14″ cavity wall employing three leaves of bricks on edge with an outer 2″ air cavity and an inner 3″ cavity filled with mud the thermal performance of the wall both as regarding damping of amplitude and depression of the maximum temperature has been extremely satisfactory. When the leaves of cavity walls are to behave as one unit structurally for taking the load, adequate metal ties should be provided. Where one of the leaves is sufficient to take the structural load lesser number of ties will be needed.

For load-bearing internal walls the same principles as for the external walls apply in so far as the structural strength and specifications are concerned. Considerations of thermal conductivity and moisture penetration are less important in the case of these walls but sound transference is significant. A thickness of less than 9″ between the tenements is unsatisfactory from these considerations.

For non-load bearing partitions a 4½″ brick wall is commonly used in this country. This requires no special foundation and can be laid directly on the floor. Thickening of the concrete floor below the wall by addition of a 6″ layer below the flooring may be advisable. Other materials that are suitable for this purpose like hollow-clay bricks, slag concrete, clinker concrete, gypsum blocks etc., have not been developed sufficiently in this country. A few examples of specifications of partitions that have been put up in these houses are indicated in Appendix III.

Ceiling Heights

It is a common conception in this country (as in many countries) that the comfort in a house in hot climates is increased by increasing the ceiling heights. The high ceilings of the stately buildings of olden days may perhaps be responsible for this belief. Use of high ceilings is based upon the feeling that large volume of air in the room will absorb the heat; that thicker layer of air between the head of the occupant and the ceiling will provide insulation against the heat radiated from the ceiling to the man's head; and that the comfort in the room depends upon humidity and as the humidity in a closed inhabited room increases due to respiration and perspiration, the comfort decreases correspondingly with the decrease in volume of air available in the closed room. There is little scientific basis for these beliefs. Experiments conducted have indicated that the increase in humidity caused by respiration and evaporation of the inmates within limits does not substantially contribute to thermal discomfort. Moreover, a boundary layer of 3″ or 4″ below the ceiling provides the necessary insulation against further heat transmission from the ceiling to the occupant by conduction and a space of 3′—4′ is sufficient, to reduce the discomfort due to radiant heat from the ceiling.

The three main reasons to be specified when fixing the ceiling heights rationally in dwellings are—

(a) there shall be adequate head room in all rooms.

(b) the proportions of all rooms shall be such that they will not cause mental discomfort to the occupant.

(c) ceiling height selected shall not prejudice physical indoor comfort.

When ceiling height is considered in terms of head room consideration of artificial lighting, fittings and ceiling fans are likely to be the limiting factors, unless the suspended fans are replaced by fans of other types. From this point of view the light fittings or the blades of the ceiling fans shall not be fixed lower than 7′ 6″ from the floor.

It is doubtful whether psychological studies have been conducted in this country to determine an acceptable minimum level for ceiling heights. It is true that temporarily an unfavourable impression is registered by a person entering a relatively small room with high ceiling. A similar feeling is possible in case of big rooms with low ceilings.

Ceiling height and ceiling temperature must be considered jointly when studying the effect of ceiling height on physical comfort indoors. These two factors govern the rate and direction of heat flow between the ceiling and the subject and in this regard the critical distance is that between ceiling and the heat-sensitive heads of the subject.

The distance from the ceiling and the temperature of the ceiling are two values that can be varied without necessarily changing the rate of heat exchanged. Radiated heat exchange depends upon the relationship between the air temperature in a room and the temperatures of the bounding surfaces. Within practical limits comfort indoors will be independent of the height of the ceiling if the temperature of the ceiling approximates that of the air in the room. This condition can be approached closely by ventilating the roof space of the dwelling in the case of pitched roofs and applying necessary insulation rather than by increasing the height of walls and ceilings.

In the case of multi-storey buildings the upper floor screens the lower floor from the effect of solar radiation on the roof and thus the thermal comfort need not be a criterion in fixing ceiling heights of lower floors. It should be borne in mind that an increased wall height increases the area of exterior wall exposed to the sun, thus increasing the heat entering the room.

It is the opinion of some authorities that a ceiling height of 9′ is adequate for all buildings in the ground floor in two-storeyed construction in both hot humid and hot arid climates. A ceiling height of 9′ is also sufficient for the top floor in hot humid regions. In hot dry regions, however, the effect of ceiling height on comfort in the case of top floor needs more experimental studies. Some experiments have recently been conducted by the Railway Testing Research Centre at Lucknow. Further experiments are proposed to be conducted in Delhi and it is proposed to construct identical rooms with ceiling heights ranging from 8′ to 12′. The temperature obtained in these rooms will be measured by means of instruments at different levels from the ceiling. These rooms will also be lived in and the physiololgical and psychological effect of various ceiling heights on the inmates will be determined to the extent possible.

It may be stated that from a purely scientific assessment of research so far carried out a ceiling height in excess of 9 ft. does not by itself materially contribute to thermal comfort but the psychological consideration may warrant a higher ceiling height. Other factors that may be relevant are the effects of depth of space above and below the blades of the fan on the breeze-throwing efficiency of the fan. Further experimentation in this direction appears necessary before a ceiling height of 9′ can be recommended. A more detailed discussion of the results of the researches conducted by the Central Building Research Institute on ceiling heights will be found in Part B of this report.

Experiments conducted by the Central Building Research Institute have indicated possibilities of a high rating from thermal point of view for houses with roofs constructed of A. C. sheets which are provided with a ceiling and ventilated ceiling space. Though tests have not been conducted on a properly designed building with adequate ventilation of ceiling space indications from the experiments so far conducted are that such a roof will give thermal comfort which will not be substantially inferior to what can be obtained with a flat roof of high capacity insulation, like the R.C.C. or reinforced brickwork roof with lime terracing or mud phuska on top. A more detailed discussion on this aspect will be found in Part B of this report.

The question of ventilating the roof space in the case of sloping roofs and of insulating the roof in the case of flat roofs follows.

Roofs

Roofs for buildings can broadly be divided into two classes: the sloping roofs and the flat roofs. It is the custom in this country to have sloping roofs for buildings in hot-humid regions with high rainfall and invaribly in the hills. In the hot-dry regions of North India, however, flat roofs are the practice.

In the hot-dry regions problems of moisture penetration in the roofs do not exist to the same extent as in the case of hot-humid regions and wet regions in the hills. In the hot-dry regions out-door sleeping at night is preferred in summer. In the case of double-storeyed buildings the occupants of the upper floor go on to the terrace for sleeping at night.

In the hot-humid regions, too, the scarcity of suitable building timber has led people to adopting flat roofs of reinforced concrete specially in urban areas.

For the ordinary low-cost houses, the roof spans rarely exceed 20′. For these spans single collared or double collared trusses are generally used in conjunction with purlins. A ceiling is usually not provided or is provided with bamboo mats, timber planks or asbestos sheets in the case of superior residences. Considerable economies in timber and greater ease of construction are possible by the adoption of nailed trusses which have become popular in the West. These trusses are spaced at 2 to 2½' centres. As these have tie-beams a flat ceiling can be easily provided without additional timber runners. From this point of view therefore such types of roof are economical and suitable where timber is available in sufficient quantities. There is need for popularising these trusses and the Forest Research Institute and the National Buildings Organisation are working in this field.

The roofing materials generally used in this country for sloping roofs are Mangalore tiles, country tiles, asbestos cement sheets and G.I. sheets thatch. In areas of comparatively low rainfall cement-stabilised-soil tiles topped with lime mortar may be suitable. This has been tried with success on an experimental scale in Hyderabad.

One type of flat roof usually adopted is of timber joists or reinforced concrete joists with tiles or natural stone laid on top and covered with a layer of lime concrete or mud phuska. This roofing has been extensively used during the war time due to the scarcity of steel. If timber is not properly seasoned and treated these are likely to be of semi-permanent nature. A variation of this specification is the roof commonly known as Madras terrace. Another specification used is reinforced concrete slabs topped over with lime concrete or mud phuska laid to slope to serve as waterproofing layer. The latter specification is universally adopted in case where cement and steel are available in adequate quantities. Considerable economy in time and materials, if not in money, is possible by the use of semi-precast and precast system of roof construction in R.C.C. This is specially the case where prestressing facilities at economical rates are available. Such constructions are of two kinds. In one type the filler slab or the topping slab over precast joists acts as temporary shuttering as well. In such cases unless the filler blocks are specially shaped a flat soffit for the ceiling is not possible. In the second type of precast construction light centering and shuttering are placed in position. Hollow blocks or bricks are placed with the necessary gaps through which the reinforcements run. Cement concrete or rich mortar is poured into the gap and then finished with concrete topping of 1½" to 2" thickness. The centering is removed after the necessary period of curing and the ceiling is plastered. The advantages claimed for this type of construction are saving in concrete and cement due to the substitution of light-weight materials in the tension zones of concrete, saving in steel due to the increased depth of the slab and saving in shuttering as the shuttering required is comparatively light and need not be so watertight as in the case of traditional concrete floors. Several variations of this type of construction are prevalent in Western countries and some have been tried in India. There is a great scope for developing both these constructions in the present context of the need for economy in cement and steel in this country. The filler blocks can either be of burnt clay, of ordinary concrete or of light weight concrete.

Reinforced brick roofs are economical and have also good thermal properties; survey of old buildings constructed to this specification has, however, shown deterioration of this type of roof due to corrosion of reinforcement 20—25 years after its construction. Researches are therefore indicated into causes of this corrosion, and specifications for materials and techniques to be used to increase the life of this type of roof are to be laid down before its large scale adoption can be advocated.

A list of specifications that have been used for roofing in houses constructed for the International Low-Cost Housing Exhibition with their unit rates per sq. ft. of covered area will be found in *Appendix VI.* Some of these houses have been tested for thermal comfort by the Central Building Research Institute and a few of the representative specifications have been assessed for their thermal properties. A built-up concrete or brick roof of about 7″ thickness has proved very good in thermal performance. Its damping effect on the amplitude of temperature variation is of the order of 65 per cent. A single asbestos-cement sheet roof has not proved advantageous from point of view of thermal comfort. If doubled, or if a ceiling is provided, however, the comfort condition improves. A detailed analysis of the thermal performance of various roofs as determined through tests carried out by the Central Building Research Institute, Roorkee will be found in part B of this report.

The greatest contribution to the heating up of the building is made by the roofs because the roof is exposed to the sun throughout the day and heat absorbed and transmitted by it is considerable. In summer, roofs receive solar radiation at a high intensity and the surface of the roof is more nearly at right angles to the sun's rays than are the walls, at least during the hotter parts of the day.

In the case of sloping roofs the roofing materials in common use are not generally thick and have low heat capacity. Consequently they heat up rapidly. Solar heat falling on the roof is carried to the inside of the roofing materials by conduction and across the roof to ceiling space by radiation and convection. Where a ceiling is provided ceiling materials conduct this heat to the ceiling surface which then acts as a low temperature radiator of considerable area.

Factors which can affect the rate of transfer of heat from the roof to the ceiling include—

(a) type of material used for roof covering;

(b) the pitch of the roof;

(c) the external colour of the roof;

(d) the shading of the roof;

(e) the insulation in the roof to ceiling; and

(f) the ventilation of the roof ceiling space.

The insulation materials available can be divided into two classes. Those which resist the passage of heat include mineral wool, straw boards, wood wool boards etc. Those which reflect radiated heat are paper-faced with aluminium foil or bright metallic paint.

On hot sunny days it is quite possible for the air in an unventilated roof to ceiling space to rise 40 to 50°F above out-door air temperature. This will produce a hot ceiling which will radiate heat into the room below. To prevent this the roof to ceiling space should be well ventilated. It is suggested that the usual limited ventilation provided at eaves and gables should be replaced by more liberal ventilation in the shape of large gable-ventilation and in severe climates by ventilating the ridges. To prevent nesting of birds and nuisance from rodents, it is necessary to cover these ventilator openings with close gauge wire netting or closely-placed louvers of asbestos cement sheet or timber.

The National Buildings Organisation's technical information series "Note on thermal movements in buildings"* discusses the main points which should be taken into account when designing flat concrete roofs so as to reduce their thermal expansion and contraction In most cases the types of cracking and other defects caused by thermal movements can be easily recognised. They show themselves most obviously on plastered surface because the plaster finishes are well suited to show them off. In unframed roofs the slab will tend to bow upward slightly owing to the higher temperature of the upper surface and at the same time the slab will spread outward. These two movements together tend to cause local cracking at the top of walls and partitions like rips when the walls are in line with the expansion movement. Otherwise a simple type of horizontal break is caused. In the case of framed buildings the roof arches as before but in panels, beams tend to bow upward and take part of the wall with them. Partitions which form panels between columns are distorted as a whole, those in line with the roof movement showing some diagonal fracture and those across the line of movement a more simple horizontal break. *Table* 7 gives a variety of treatments that have been suggested by the Building Research Station at Watford for protection against heating as well as for water-proofing. Alongside these recommendations are given the maximum temperature attained below the protective covering and above a 4″ concrete slab under conditions specified in *Table* 7.

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*Under publication.

To reduce the heat falling on the roof shading is the obvious solution. This is not possible in the case of flat roofs of high buildings. The next possibility is to reduce the quantity of heat absorbed by the surface. The sun's heat that falls on any surface is partly absorbed and partly reflected. The heat reflected is a factor of the colour of the surface. *Table* 9 gives such reflectivity coefficients calculated for various coloured materials. It will be seen from this table that a white colour has very high reflective properties. It will, therefore, be advantageous to colour the exposed surface of the roof white or nearly so.

TABLE 7

MAXIMUM TEMPERATURES BENEATH VARIOUS FLAT ROOF COVERINGS ON AVERAGE SUNNY DAY IN ENGLAND

(Max. shade temperature approximately 80° F.)

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Roof Coverings	Max. Temp. °F
3/4 in. asphalt-sanded finish	110
3 layers of felt-gritted	110
3/4 in. asphalt-1 in. mortar screed	90
3 layers of felt-gritted-1/2 in. mortar screed	93
1/2 in. fibre board -3/4 in. asphalt-sanded finish	87
3 layers of felt-sanded with white grit	85
3 layers of felt-gritted-1 in. mortar screed	85
3/4 in. asphalt-white spare chippings.	80
3/4 in. asphalt-2 in. layer gravel	79
1 in. cork -3/4 in. asphalt-sanded finish	78
3/4 in. asphalt-limewash	75
2 in. cork-3/4 in. asphalt—sanded finish	73

Mortar screeds are fairly effective in reflecting heat but in practice some of them get dirty and thus lose their efficiency.

Asphalt treatment, being of black colour, contributes very much to the heating up of the roof surface. The following recommendations for application of lime washes for such roof have been given by the Building Research Station, U. K. where white chippings or other reflective material cannot be used to blind the surface.

"Qick lime tallow mixtures do not cause the ill effects to bituminous roofs which many other whitening treatment do. The mixture should be prepared by first breaking up a white high calcium quicklime into small lumps and adding 10 per cent. by weight of tallow, shredded and placed on top of the heap. Sufficient cold water is then added to melt the tallow and disperse it within the mass, without becoming charred and destroyed. When slaking is complete, sufficient water is added to enable the mass to be worked up into a stiff cream which can, if desired, be screened to remove coarse lumps. Only a thin film is needed to provide the white surface and the cream is therefore thinned considerably with water before use. The dark surface to which it is applied is barely obscured while the limewash is wet; it becomes white immediately on drying.

Additions of materials such as glue, size etc. intended to improve durability are almost certain to have bad effects on the bituminous surface and should not be used.

When tallow is difficult to obtain, a safe alternative is wool grease, which should be used in the same portions and by the same method. The wool grease is not as readily dispersed as tallow, nor unfortunately is the product as durable. Higher proportions of wool grease should not be employed, for they may damage the bitumen surface".

The next method for protection of the roof from heating is through providing an insulation layer on top of the concrete slab. For this purpose hollow clay blocks and porous concrete screeds have been tried. It will be necessary to provide them with suitable expansion joints to prevent them from lifting.

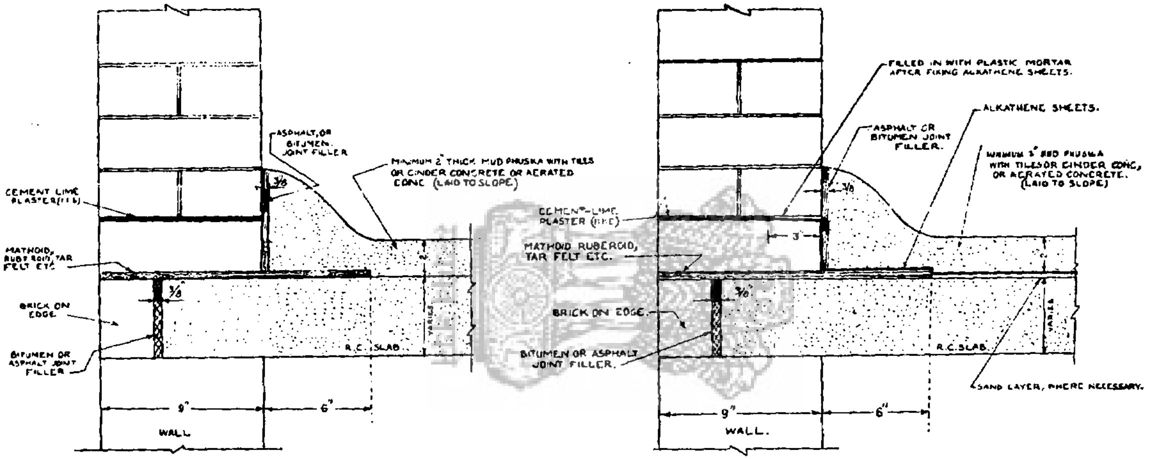
In the hot-dry regions, where there is a marked day-night temperature range, buildings used during the day should have a form of roof construction which will warm up slowly. The extent of this time-lag depends on the mass of the roof—the heavier the roof the longer the lag. In the case of a 4" concrete slab, the theoretically calculated time-lag is about 2½ hours; 8" hollow concrete slab has a time-lag of about 5 hours and an 8" solid slab about 6 hours. For rooms which are used only at night, roofs should be capable of cooling down as rapidly as possible. For this purpose a light structure roof is appropriate.

When all reasonable precautions have been taken, roof movements and the differences between roof movements and the thermal movements of the walls and other connected parts will be minimised but not entirely avoided. Some movement must always occur due to changes in air temperture. It is, therefore, necessary to incorporate expansion joints at suitable intervals to prevent damage to the structure. The expansion joints should be inserted not only in the roof but also in the external walls and should extend inward at least part of the way through the building to enable the stresses of expansion to be distributed without causing obvious cracking. The best course is to cut right through the building down to foundation level.

Observations made on most of the flat-roof constructions in the low cost housing exhibition buildings indicate that the greatest trouble experienced regarding moisture penetration is at the junction of walls and roofs. The wetting of the slab due to moisture penetration has not been noticed to any considerable extent. It was seen that in most cases, where water-proofing with lime-concrete or mud-phuska was provided, there was very little leakage from the slab itself. It therefore appears that more consideration is required in the design of the junction of walls and roofs of buildings and also of places where construction joints have been left. A few illustrative sketches giving suggestions as to how these joints may be treated to avoid leakages are given in *Plates* 2 and 3.

In the hot humid region where rainfall is heavy more efficient water proofing may be necessary. The most successful water-proofing treatment in all countries has been through use of bitumen or tar-impregnated felts or hessians. They are, at present comparatively expensive in India. Recently alkathene sheets have been tried on an experimental basis in the Central P.W.D. in Delhi. The results appear to be promising. There is scope for researches aimed at development of indigenous water-proofing materials for such climates.

Another cause of leakage or of dampness in walls is defective detailing and construction of parapet walls. It is not the practice in this country generally to provide dampproof courses between parapet and main walls. The copings are also made of ordinary bricks and plastered over with mortar which usually cracks and admits moisture. The junction of the walls and the roof is also often incorrectly designed. These are some of the reasons why the external walls of buildings with flat roofs are found to be damp. It has also been held that plastering both sides of parapet walls lead to damp conditions because the water which enters through a crack cannot readily evaporate. It has, therefore, been suggested by certain authorities that parapet walls may be plastered only on one side so that water entering through the cracks can easily evaporate from the opposite surface. Illustrative sketches of correct and incorrect details of parapet walls will be found in *Plates* 4 and 5.

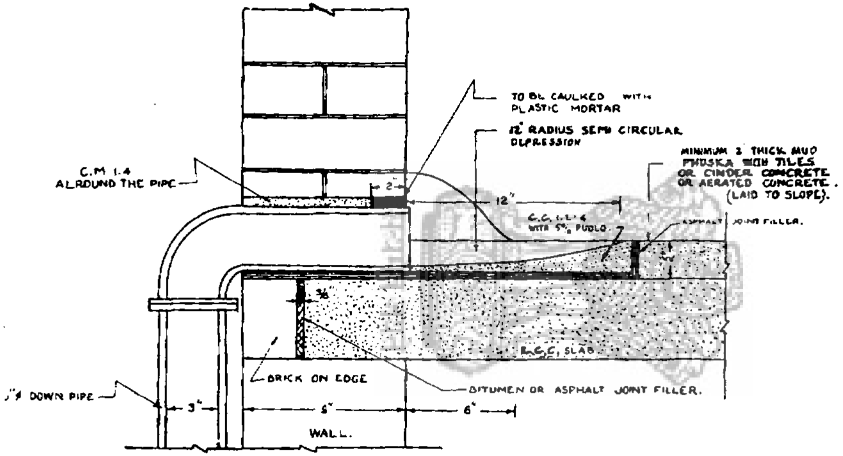

ASPHALT, OR BITUMEN JOINT FILLER
MINIMUM 2" THICK MUD PHUSKA WITH TILES OR CINDER CONCRETE OR AERATED CONC (LAID TO SLOPE)
CEMENT LIME PLASTER(1:1:6)
3/8
MATHOID, RUBEROID, TAR FELT ETC
3/8
BRICK ON EDGE
BITUMEN OR ASPHALT JOINT FILLER
R.C. SLAB
VARIES
9"
6"
WALL
FILLED IN WITH PLASTIC MORTAR AFTER FIXING ALKATHENE SHEETS.
ALKATHENE SHEETS.
ASPHALT OR BITUMEN JOINT FILLER.
MINIMUM 3" MUD PHUSKA WITH TILES OR CINDER CONC, OR AERATED CONCRETE. (LAID TO SLOPE)
CEMENT-LIME PLASTER (1:1:6)
3/8
3"
MATHOID RUBEROID, TAR FELT ETC.
3/8"
BRICK ON EDGE.
BITUMEN OR ASPHALT JOINT FILLER.
R.C. SLAB.
VARIES
SAND LAYER, WHERE NECESSARY.
9"
6"
WALL.

DETAIL OF JUNCTION OF WALL & ROOF FOR FLAT TERRACES.

MEMBRANE WATER PROOFING WITH ALKATHENE

PLATE No 2

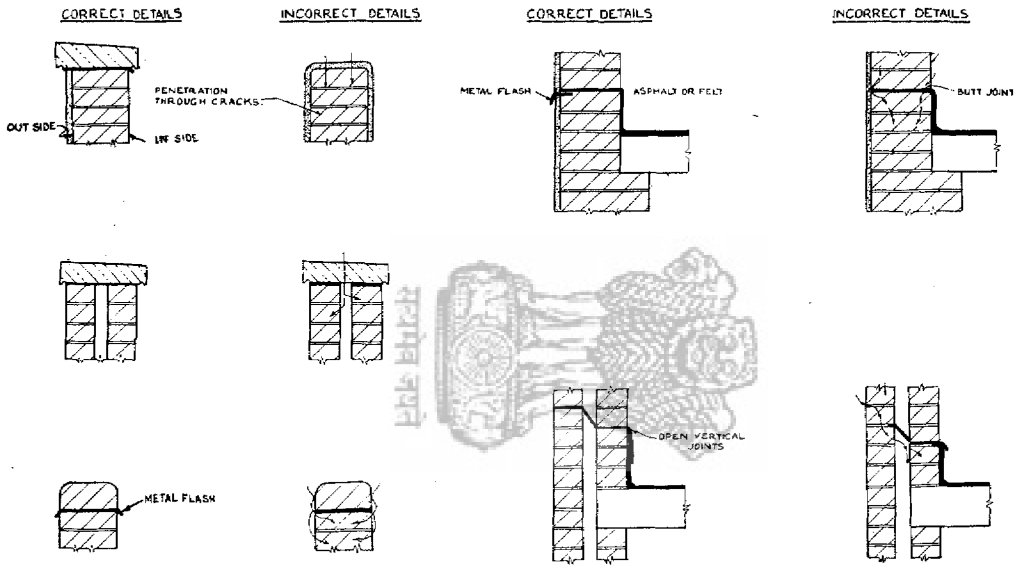
PLATE 2



DETAIL OF JUNCTION OF WALL & ROOF SHOWING POSITION OF RAIN WATER PIPE

PLATE No 3.

PLATE 3

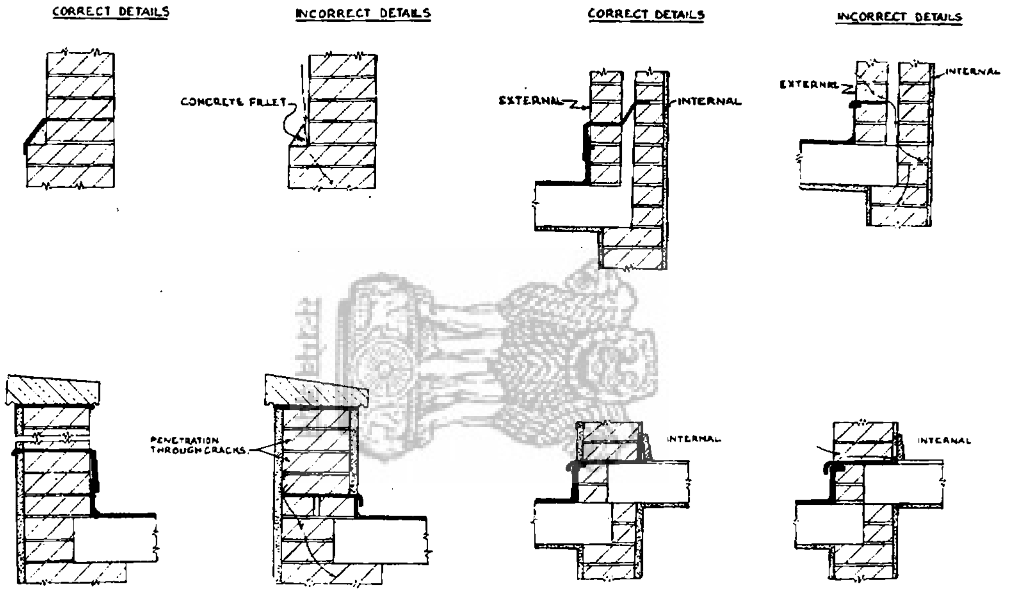


DAMP PROOFING OF WALLS

PLATE No. 4

सत्यमेव जयते

PLATE 4



DAMP PROOFING OF WALLS

PLATE No 5

PLATE 5

सत्यमेव जयते

11.—*Doors and Windows*

The function of a window is to provide ventilation and daylighting.

In the case of ventilation the requirements for hot dry regions and hot humid regions vary. In the case of hot dry regions considerable heat penetrates through the windows because it admits sun's rays and also offers less resistance to the passage of heat than solid walls. The thermal discomfort in the house in summer therefore increases in direct proportion to the area of window space exposed to the sun. Structural overhangs partly protect the window openings but these are of dubious value because when they are designed to keep off the sun in summer efficiently they usually cut off needed sunlight in winter too. Adjustable louvers or vertical and horizontal fins are preferable from this point of view. Another possibility is to have shutters partly glazed and partly panelled or have two shutters one glazed and the other panelled or venetioned. Shading by suitable trees or shrubberies also helps. Use of heat-absorbing glass is another possibility.

As mentioned earlier, it is unnecessary to provide excessive window space in houses in the hot arid regions. As the cost of a window is four to five times the cost of the wall, it is cheaper to provide less window space. It has been recommended by some authorities that the minimum window space for living rooms or bed rooms in hot-dry areas need not be more than 10 per cent. of the floor area but to take care of the humid parts of the year it is preferable to fix a window range of 10-20 per cent. of floor area as desirable window area. Depending on the length of the period during which the weather is humid sufficient cross ventilation and natural ventilation facilities will however have to be provided. This can be done by windows on one side and adjustable ventilators or fan lights on the opposite or adjacent walls as necessary.

In the case of hot and humid regions the considerations are quite different. The difference between the indoor and the out-door temperatures is not much. The humidity in the atmosphere makes the cooling of the body by evaporation impossible unless it is aided by breeze. The recommended minimum window space for such climates vary from 15 to 30 per cent. depending upon the orientation and design of the buildings in relation to wind direction and velocity. Cross ventilation is most important under such climates and this sometimes necessitates provision of window-space far above the minimum.

Permanent ventilation in the hot-arid regions is not of great use and is often a source of great discomfort. These ventilations are, however, necessary in rooms serving as kitchens, bath rooms, W. Cs and stores. In the case of living rooms, where artificial heating by fire is usually done during winter months a certain area of permanent ventilation is desirable. In the case of bed rooms, these are unnecessary because when ventilation is needed the window can as well be opened. In the case of hot-humid regions permanent ventilation is of great value especially where some of the windows have to be closed from the point of view of privacy or security and when the window space provided from economical considerations does not permit good cross ventilation.

By positioning the windows in the adjacent walls the flow of breeze is concentrated in one corner which leaves a major portion of the room as dead spot. A staggering of openings will lead to fuller ventilation in the room.

When providing through ventilation by means of windows on parallel walls it will be advantageous to put a smaller window on windward direction and a larger one in leeward direction as this causes a spill-way action and the velocity of the air movements in the room is increased appreciably. A fuller discussion of the effect of placing of windows on ventilation rates in buildings will be found in part "B" of this report.

From the point of view of day-lighting the usual window areas provided in both hot-arid and hot-humid regions are quite ample to provide the minimum. The problem in the tropics is to keep the glare out. In hot-humid regions the sky is often covered by clouds and reflects considerable heat and glare into the room. This has to be prevented by means of louvres or fins which will admit the breeze at the same time keeping out the glare. Windows in such cases can be kept as low as possible so that the breeze is admitted inside at the level at which people live and work. From this consideration the height of the sill of the window may be between 2′ to 3′. The ventilators or fan lights provided should be near the ceiling level so that natural ventilation will take place through "stack effects". In the case of hot-arid regions the sky is usually blue and does not reflect much light. The ground is often not covered with green vegetation and so reflects quite a lot of heat and light. The traditional method of preventing this was by keeping windows small with their sills at very high levels, and by using perforated marble or stone screens. The former has certain aesthetic disadvantages and the occupants do not get full use of the window in not being able to look out during the cooler periods of the year and in the evenings and in mornings. It is, therefore, to be preferred that bottom of the window level in the case of hot-arid regions may be kept at about 3′ from the floor level. The bottom portion of the window may be shaded from the effect of the glare by either panelling the lower portion of the shutter or by providing artificial screens or curtains.

The sizes of doors provided are often bigger than what are functionally needed. The variation in the sizes of doors and windows provided in the exhibition houses is indicated by some examples given in *Appendix V*. There is a need for standardising door and window openings and the Indian Standards Institution is working along these lines.

In low-cost housing considerable economy is possible in the case of panel doors and windows by the substitution of cheaper panels in place of the traditional timber. Suitable alternatives are asbestos, cement sheets, hard board, plywood etc. The latter two are not very cheap in the present market but have potentialities in economy with increased development and competitive production of the products. There may be some objection to the use of these materials in the external doors and windows from the point of view of security but this should not preclude their use for internal communication doors in low cost houses.

A statement giving the various specifications adopted for doors and windows in the low-cost housing exhibition and their corresponding unit rates will be found in *Appendix* VI

Plastering

The function of the external plaster is to protect the wall from absorbing and letting in water, to cover the deficiencies in brickwork and to give a pleasing uniform appearance of any desired colour. For this purpose, it is necessary that the external plaster should be reasonably even and should be free from cracks and defects. Of late the practice in plastering has been to use cement plasters of richness depending upon the grading of sand and the corresponding workability. Cement plasters are subject to crazing and cracking. Between cracks they are reasonably impermeable to water. Rain water penetrates through these cracks and once it enters the brickwork, it cannot easily evaporate due to the general impermeability of the overlying plaster layer. The workability of cement mortar is also not high with the result that often a rich mix is used which again leads to greater shrinkage cracks. To obviate this the solution is to add lime in partial replacement of cement or alternatively use mortars with hydraulic lime or lime rendered hydraulic by the addition of pozzolanic agents. For external use in high exposure a cement-lime plaster of the consistency 1:1:6 has been recommended. In situations where the exposure is not so great a cement lime plaster of 1:2:9 or 1:3:12 can be used. Recent practice in other countries has been to eliminate time by the use of mortar plasticisers. These are air-entraining agents which entrain small stable air-bubbles inside the mortar. These bubbles give the necessary workability and plasticity to the mortar, thus reducing shrinkage cracks.

For internal plaster a cement time plaster 1:2:9:, 1:3:12 or one of the plasters using lime, sand, surkhi, or ash is suitable. Plasters used in other countries have gypsum as their base. These have not been developed to any great extent in this country but has great potentialities in the context of the present shortage of cement and non-availability of reliable lime. Researches and development work in this line are necessary and are recommended. Recommendations for plasters suitable for external and internal application drawn up with a view to economising the use of cement in constructions are given in *Table* 8.

TABLE 8

MORTARS FOR PLASTERS

S. No.	Situation	Composition of mortar (proportions by volume)	Class of lime
1	External plaster below damp-proof course	1 cement, 1 lime and 6 sand	B or C
2	External plaster above damp-proof course.	1 cement, 2 lime and 9 sand	B or C
3	Internal plaster on all walls	(*i*) 1 lime, 2 sand	A
		(*ii*) 1 lime, 1 surkhi, 1 sand	B or C
		(*iii*) 1 lime, 1 ash, 1 sand	B or C
		(*iv*) 1 lime, 2 surkhi	B or C
		(*v*) 1 lime, 2 ash	B or C
		(*vi*) 1 cement, 2 lime and 9 sand	C
		(*vii*) 1 cement, 3 lime and 12 sand	B

As in the case of roofs, the colour of the external wall has a great bearing on the heat penetration inside the building. The reflectivity-co-efficient for various types of renderings with different colours have been measured by various authorities and these are given in *Table* 9.

The reflectivity co-efficients as determined by the Central Building Reasearch Institute, Roorkee in their experiments in Delhi are given in Part B of this report.

TABLE 9

Material	Heat Reflectivity per cent	
	Solar	Low-temperature
Whitewash	80	.
White lead paint	71	11
Asbestos-cement cleaned after exposure	60	.
White marble	54	5
Light-red clay tile	53	.
White sand-lime brick	50—59	.
Buff clay brick	48	.
Aluminium	47	96
Aluminium paint	46	33—73
Galvanized iron, new	36	72—77
Concrete tile, uncoloured	35	.
Asbestos-cement aged one year	29	5
Cement mortar screed	27	.
Red clay brick	23—30	5—7
Green leaves	21—29	1
Concrete	.	6
Plaster	.	9

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Some General observations on novel techniques adopted in the construction of low-cost houses put up in the Exhibition.

Reinforced cement concrete roofing provided without any waterproofing arrangement depending only on the slope of the roof for preventing rain penetration has not met with much success in the buildings constructed in the low-cost housing exhibition. Some of them have leaked, possibly on account of the concrete not being dense enough. Invariably the junction of the wall and the roof have separated due to expansion which becomes considerable in the case of concrete slabs without insulation on top.

It has been noticed that cavity walls constructed with clinker or cinder aggregate in two leaves of 2½″ thickness each with a cavity of 3″ between has proved structurally strong enough for single-storey construction. No moisture penetration inside such walls has been noticed.

Hollow cinder blocks have proved satisfactory from the point of view of structural stability moisture penetration and durability and provide a good backing for internal plaster. This material seems to have great scope in areas where bricks are scarce or expensive and cinder abundant.

The house constructed with Aerocem blocks (*i.e.* aerated concrete of cement, sand and ⅜″ aggregate) has proved satisfactory from the point of view of thermal comfort and moisture penetration. There are no visible cracks in the walls. The ceiling consisting of aerated cement plaster on hessian cloth cannot be said to be satisfactory as.—

a. it is observed that it shows a tendency to separate from the wall and special beadings will be necessary at this junction if the ceiling is not to look unsightly.

b. electric wiring fixed to the ceiling has tended to break loose.

These defects can however be removed by improvements in design.

The system of fixing door and window shutters to the concrete frames through embedded wood blocks cannot be said to be satisfactory as there are indications that these get loose. There are also separation cracks between the concrete chowkat and the masonry which can be controlled by grouting with plastic cement.

The vacuum concrete system has proved structurally satisfactory and the house constructed of this material is found to be reasonably water tight, but due to the thinness of the slab and lack of insulation the roof slab has tended to separate from walls at the junctions. Treatment of such cracks with mastic may perhaps remedy the situation but this is likely to recur with every change of season. This is the natural outcome of the concrete getting hot due to its thinness and consequent expansion.

The system of roof construction with precast concrete joists and foamed concrete fillers has proved satisfactory. It has also proved water-tight with traditional methods of water proofing using mud phuska. Hardly any separation cracks have been noticed at the junction of the roof and the walls in this construction.

The bamboo reinforced concrete columns and panels used in the construction of a certain house have so far stood well. In some places where slight cracking has been seen it has been noticed that the bamboo inside has dried up and lost its tensile properties. It is doubtful whether this system of construction can be considered to be permanent and further observations are needed to ascertain its probable life.

The jack arch roof on concrete joists provided in one house has shown cracks. The corrosion of the steel ties has also been noticed. Even slight settlement of walls can lead to cracks in the arch and this has been noticed in some parts of the roof of this house.

Gypsum blocks have proved satisfactory for internal walls but while used externally these blocks have shown cracks and erodibility. For external use they may require the same non-erodable plaster as is necessary for mud masonry.

The cavity wall construction with 1½″ precast concrete slabs adopted by West Bengal Government has proved efficient from the point of view of moisture penetration but enquiry from the inmates indicated that the house becomes very hot in the summer.

APPENDIX I

STATEMENT SHOWING SPECIFICATIONS THAT HAVE BEEN USED FOR FOUNDATIONS IN THE LOW COST HOUSES WITH THEIR UNIT COST

Sr. No.	Specifications for foundation concrete and base footings	Unit cost per 100 cft.
		Rs.
1	Mud concrete with brick ballast (1½" gauge)	49
2	Rubble stone in mud mortar	55
3	Rubble stone in stabilised soil with 5% cement	70
4	Cement concrete 1:6:12 (1 cement, 6 Jamna sand, 12 brick ballast 1½" gauge)	85
5	Lime concrete 1:2:2 (1 lime, 2 ashes, 2 Jamna sand, with 1½" size brick ballast and 40% mortar)	86
6	Lime, cement concrete; ½:1:6:12 (½ lime, 1 cement, 6 Jamna sand and 12 brick ballast, 1½" gauge	87
7	Lime concrete 1:3 (1 lime 3 Jamna sand) using 1½" brick ballast and 40% mortar	88
8	Lime concrete 1:1:1:9 (1 lime, 1 cinder, 1 Jamna sand, 9 brick ballast)	91
9	Lime concrete 1:3 (1 lime, 3 Jamna sand) using 1" gauge Delhi quartzite stone ballast and 40% of mortar	93
10	Cement concrete 1:5:10 (1 cement, 5 Jamna sand, 10 Delhi quartzite stone ballast and 40% mortar	100
11	Lime concrete 1:2:7 (1 lime, 2 cinder, 7 Delhi quartzite stone ballast 1½" gauge	108
12	Cement concrete 1:4:8 (1 cement, 4 Jamna sand, 8 Delhi quartzite stone ballast 1½" gauge)	109
13	Cement concrete 1:3:6 (1 cement, 3 Jamna sand 6 Delhi quartzite stone ballast 1½" gauge	126
14	Cement concrete 1:3:6 (1 cement 3 Badarpur sand, 6 Delhi quartzite stone ballast 1½" gauge	140
15	Reinforced cement concrete 1:2:4 (1 cement, 2 Badarpur sand, 4 Delhi quartzite stone ballast 3/4" gauge excluding cost of reinforcement	196

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Sr. No.	Specification for masonry in foundation and plinth	Unit rate per 100 cft.
		Rs
1	Rubble stone masonry in lime mortar 1:3 (1 lime, 3 Jamna sand)	60
2	Gypsum block masonry in blocks of 16"×8"×8" with gypsum mortar	60
3	2nd class brick work in mud mortar	69
4	Mixed class brick work in mud mortar	73
5	2nd class brick work in cement mortar (1 cement, 8 Jamna sand)	88
6	2nd class brick work in lime mortar 1:3 (1 lime, 3 Jamna sand)	93
7	2nd class brick work in cement mortar 1:6 (1 cement and 6 Jamana sand)	94
8	1st class brick work in cement mortar 1:8 (1 cement and 8 Jamna sand)	95
9	Random rubble masonry in lime mortar (1:3) 1 lime, 3 Jamna sand with Delhi quartzite stone	96
10	Random rubble masonry in cement mortar 1:6 (1 cement, and 6 Jamna sand) with Delhi quartzite stone	97
11	Mixed class brickwork in lime cinder mortar 1:1:2: (1 lime, 1 cinder 2 Jamna sand)	98
12	Mixed class brick work in cement mortar 1:6 (1 cement, 6 Jamna sand)	98
13	2nd class brick work in cement mortar 1:7 (1 cement, 7 Jamna sand)	99
14	Firxt class brickwork in lime mortar 1:3 (1 lime, 3 Jamna sand)	100
15	1st class brick work in cement mortar 1:6 (1 cement, 6 Jamna sand)	101

Sr. No.	Specification for masonry in foundation and plinth	Unit rate per 100 cft.
16	Cement concrete hollow blocks 8" thick filled in with cement concrete 1:5:10 (1 cement, 5 Jamna sand, 10 Delhi quartzite, 1½" ring) laid in 1:1:9 lime cement mortar, 1 lime, 1 cement, 8 Jamna sand .	107
17	Cement concrete 1:4:8 blocks, filled in with cement concrete 1:4:8 (1 cement, 4 Jamna sand, 8 Delhi quartzite stone ballast) .	109

APPENDIX II

STATEMENT SHOWING VARIOUS SPECIFICATIONS USED FOR SUPERSTRUCTURE IN LOW COST HOUSES PUT UP IN THE EXHIBITION.

Sr. No.	Specifications	Unit cost per % sq. ft Rs.	as.	ps.
1	Second class brick work in cement mortar 1:4 (cement 1, Jamna sand 4) 3" thick upto 2' 9"; wattle walling, cement plastered 1:6 (1 cement, 6 Jamna sand) and lime punned over this height	28	4	0
		(Average rate o wall).		
2	Gypsum block masonry in blocks of 16"×8"×8" laid in gypsum mortar	40	0	0
		(Rate quoted by Builder).		
3	Single wattle and split bamboo crete	55	0	0
4	9" thick walls of second class brick work in mud mortar .	59	4	0
5	Rubble masonry in mud mortar in 12" thick walls . .	60	0	0
6	9" thick first class brick work in mud mortar . . .	64	8	0
7	Hollow cinder-cement blocks 8" thick laid in 1:6 cement mortar (1 cement 6 Jamna sand)	66	10	0
8	Hollow cement concrte blocks 8" thick laid in 1:5 cement motar (1 cement 5 Jamna sand)	67	0	0
9	½" thick vertical wooden boards but jointed with heading, with 3"×3" scantlings fixed to 4"×4" wooden posts .	68	0	0
		(Rate quoted by the builder)		
10	Solid concrete blocks 16"×8"×2½" and 3"×8×2½" laid in cement mortar 1:4 (1 cement, 4 Jamna sand) for cavity walls 8" thick	73	0	0
11	9" thick second class brick work in cement mortar 1:6 (1 cement, 6 Jamna sand)	70	8	0
12	Pillar and panel construction, 8"×8" pillars in cement concrete 1:2:4 (1 cement, 2 Badarpur sand, 4 Delhi quartzite stone ballast ¾" gauge) and panels of 1½" thickness in cement concrete 1:2:4: with bamboo reinforcement . .	73	0	0
13	9" thick mixed class brick work with cement mortar 1:6 (1 cement 6 Jamna sand)	73	8	0
14	9" thick second class brick work in cement mortar 1:8 (1 cement, 8 Jamna sand)	73	8	0
15	8" thick cement concrete hollow blocks laid in lime cement mortar 1:1:10 (1 lime, 1 cement, 10 Jamna sand) . .	77	0	0
16	9" thick second class brick work in lime mortar 1:3 (1 lime, 3 Jamna sand)	77	4	0
17	Reinforced beam and column construction 8"×8" section columns in 1:2:4 cement concrete (1 cement, 2 Badarpur sand, 4 Delhi quartzite stone ballast ¾" gauge) with R.C.C. beam at roof level, and 9" thick panels filled in with brick work in mud mortar	77	4	0

Sr. No.	Specifications	Unit cost per % sq. ft. Rs.	As.	P
18	Pillar and panel construction 14″ × 14″ brick pillar in cement mortar 1:8 (1 cement, 8 Jamna sand) and second class brick work 9″ thick in panels laid in 1:8 cement mortar. The pillars are reinforced with 2 No. 3/8″ bars	78	0	0
19	9″ thick wall of second class brick work in lime cinder mortar 1:1:2 (1 lime, 1 cinder and 2 Jamna sand)	78	0	0
20	9″ thick first class work in cement mortar 1:6 (1 cement, 6 Jamna sand)	82	8	0
21	9″ thick first class brick work in lime mortar 1:3 (1 lime, 3 Jamna sand)	82	8	0
22	13½″ thick third class brick work in mud mortar	84	6	0
23	3″ thick R.C. concrete panel walls 1:3:6 (1 cement, 3 Jamna sand 6 Delhi quartizite stone ballast ¾″ gauge) reinforced with ¼″ mild steel bar at 14″ C.S. and 9″×9″ columns in 1:2:4 cement concrete reinforced with ¼″ bars	85	0	0
24	8″ thick cinder concrete hollow blocks, laid in cement mortar 1:4 (1 cement, 4 Jamna sand)	90	0	0
25	13½″ thick mixed class brick work in mud mortar	94	0	
26	Random rubble masonry in lime mortar 1:6 (1 lime, 6 Jamna sand in walls 12″ thick)	107	0	0
27	Single thin corrugated arch in the shape of centenary made by placing the layers of concrete on hession	175 (now known probably).	0	0
28	Double sheet corrugated arch in the shape of centenary made of thin layers of concrete on hession	175 Probably 250	0	0

APPENDIX III

STATEMENT SHOWING SPECIFICATION FOR NON-LOAD BEARING WALLS AS PARTITIONS WITH THEIR UNIT COST.

Sr. No.	Specifications	Unit cost per % sft. (in Rupees)
1	Half brick work in cement mortar 1:4 (1 cement, 4 Jamna sand)	50
2	4″ special T-bricks laid in cement mortar 1:6 (1 cement, 6 Jamna sand)	50
3	Half brick work in cement mortar 1:3 (1 cement, 3 Jamna sand)	58
4	Cinder concrete hollow block masonry in cement mortar 1:4 (1 cement, 4 Jamna sand). The blocks are 4″ thick.	60

APPENDIX IV

STATEMENT SHOWING THE SPECIFICATION THAT HAVE BEEN USED FOR ROOFING THE LOW COST HOUSES PUT UP IN THE EXHIBITION, WITH THEIR COST PER% SQ. FT. (HORIZONTAL COVERED AREA)

Sr. No.	Specifications	Unit cost per % sq. ft. of horizontal covered area.
		Rs.
1	Thatched roof 6" thick tied down to bamboo frame . . .	50
2	Asbestos cement sheet roofing laid over angle-iron purlines . .	96
3	4½" thick jack arch roof supported over precast R.C.C. beams (1: 2 :4) with lime concrete 1 : 3 (1 lime, 3 Jamuna sand) in haunches and 3" over crown.	112
4	Precast 2" thick cement concrete tiles (1 : 2 :4) 1 cement, 2 Badarpur sand, 4 Delhi quartzite stone ballast ½" gauge, laid over R.C.C. battens 7" x 3½" placed 2'—0" c.s. and top finished with 2 coats of bitumen and 4" thick mud on top.	127
5	Manglore tile roofing over wooden scantlings	132
6	Corrugated galvanised iron sheet roofing 24 B.W.G., with 6" thick thatch covering over it.	140
7	Semi-precast roof of 2" thick precast slabs placed over R.C.C. T beams with 1½" thick top concrete cast in situ..	150
8	Madras terrace roof over R.C.C. precast rafters, brick on edge, and 3" thick lime concrete laid over with 2 layers of tiles in 1 : 3 cement mortar.	Rate not known.
9	4" thick reinforced cement concrete (1 : 2 :4) 1 cement, 2 Badarpur sand, 4 Delhi quartzite stone ballast ½" gauge slab including 5 lbs steel per cft, rendering of exposed surfaces, centering and shuttering .	167
10	4½" thick reinforced brick slab in 1 : 3 cement mortar (1 cement, 3 Jamuna sand) with 4½" thick lime terracing over it . . .	175
11	Agra red stone slabs 1½" thick laid in 1 : 4 (cement mortar 1 cement, 4 Jamuna sand) over wooden battens, and mud phuska on top . .	180
12	Hollow burnt clay brick with reinforcement laid over with patent stone on top	Rate not known.
13	Kotah stone double slabs set on inverted mild steel T-Sections and joints filled in with cement and bitumen, including lime terracing over it	257

APPENDIX V

STATEMENT SHOWING VARIOUS SIZES OF DOORS AND WINDOWS ADOPTED IN LOW COST HOUSING EXHIBITION

Sr. No.	Size of doors	Size of windows
1	2′—3″ x 7′—0″	1′—6″ x 3′—0″
2	2′—6″ x 6′—3″	1′—6″ x 4′—0″
3	2′—6″ x 6′—6″	2′—0″ x 3′—0″
4	2′—6″ x 6′—8″	2′—0″ x 5′—6″
5	2′—6″ x 7′—0″	2′—0″ x 5′—9″
6	2′—6″ x 8′—0″	2′—6″ x 3′—0″
7	2′—9″ x 6′—6″	2′—6″ x 3′—6″
8	2′—9″ x 6′—9″	2′—6″ x 4′—0″
9	2′—9″ x 7′—0″	3′—0″ x 3′—0″
10	2′—10″ x 6′—6″	3′—0″ x 3′—6″
11	3′—0″ x 6′—6″	3′—0″ x 3′—9″
12	3′—0″ x 6′—9″	3′—0″ x 4′—0″
13	3′—0″ x 7′—0″	3′—0″ x 4′—0″
14	3′—0″ x 8′—0″	3′—3″ x 4′—3″
15	3′—0″ x 8′—9″	
16	3′—3″ x 6′—6″	3′—8″ x 2′—6″
17	3′—6″ x 6′—6″	3′—10″ x 3′—0″
18	3′—6″ x 7′—6″	4′—0″ x 4′—0″
19	3′—6″ x 8′—9″	4′—0″ x 5′—0″
20	3′—9″ x 6′—6″	5′—0″ x 4′—6″
21	4′—0″ x 6′—9″	6′—0″ x 4′—0″
22	4′—8″ x 6′—6″	7′—3″ x 2′—6″
23	6′—0″ x 6′—6″	7′—6″ x 2′—0″
24	7′—3″ x 9′—0″	7′—6″ x 5′—0″

APPENDIX VI

STATEMENT SHOWING SPECIFICATIONS ADOPTED FOR DOORS AND WINDOWS IN LOW COST HOUSES PUT UP IN THE EXHIBITION, WITH THE COST PER SQ. FT.

Sr. No.	Specifications	Unit cost per sq. ft.		
		Rs.	a.	p.
1.	Providing and fixing bamboo jaffri with frames including complete fittings.	1	5	0
2.	Providing and fixing soft wood plain jaffri with frame including fittings	1	13	0
3.	1" thick soft wood battened and braced ,"Z" pattern shutters with 3" x 3" frame indoors	1	14	0
4.	1½" thick soft wood frame and shutters provided with G. I. panels and complete with fittings.	2	0	0
5.	1¾" thick soft wood door and windows with frames and fittings (Top and bottom clearance)	2	1	0
6.	1¾" thick soft wood battened and braced doors & windows with frames including the fittings.	2	1	0
7.	R.C.C. frame and 1¼" thick soft wood windows half glazed and half panelled	2	3	0
8.	1¼" thick soft wood panelled doors & windows with synthetic wood panels and iron fittings	2	3	0
9.	R.C.C. concrete frame, with 1¼" thick soft wood panelled doors shutters panels of galvanised iron sheet.	2	4	0
10.	R.C.C. frame, with 1½" thick soft wood doors & windows panelled complete with iron fittings	2	5	0
11.	1½" thick soft wood doors ⅓ glazed and ⅔ panelled with soft wood frame and complete iron fittings.	2	6	0
12.	1½" thick soft wood panelled doors & windows with salwood frames including iron fittings	2	7	0
13.	1½" thick soft wood doors half glazed and half panelled with frames including complete iron fittings	2	8	0
14.	1½" thick soft wood half panelled and half wooden jali indoors and windows with iron fittings	2	8	0
15.	1½" thick soft wood bottom and top panelled and middle portion in fly proof gauge.	2	9	0
16.	1½" thick 1st class teak wood battened and braced doors and window including frames and iron fittings.	2	11	0
17.	1½" thick teak wood panelled doors and windows with frame 4" × 2" and black sheet panels.	2	13	0
18.	Second class teak wood doors 1¼" thick with frames and plain asbestos cement sheet panelling with iron fitting	2	13	0
19.	1½" thick salwood panelled doors with frames including iron fittings	2	15	0
20.	1½" thick teak wood fully glazed windows with frames & iron fittings	3	1	0
21.	1½" thick soft wood windows fully glazed with iron fittings, blocks and cleats	3	3	0
22.	1½" thick second class teak wood panelled doors and windows with 3" x 3" frames including iron fittings	3	5	0
23.	1½" thick second class teak wood doors 1/3 glazed and 2/3 battened including iron fittings.	3	5	0
24.	1½" thick salwood fully glazed windows with frames and including complete iron fittings	3	6	0

APPENDIX VII

STATEMENT SHOWING THE HEIGHT OF CEILING ABOVE THE FLOOR LEVEL

House No.	Specifications of roof	Height of ceiling	Remarks
2	9½″ thick roof: 6″ R.C.C. slab with flat bricks on top	10′ 0″	
3	Corrugated A.C. sheets	14′ 0″	Average height
4	9″ thick roof:—4½″ R.C.C. slab with 4½″ thick lime concrete with bitumen wash on top	10′ 5″	
6,8	5″ thick:— Two corrugated concrete curved shells 1½″ each with an air gap of 2″	10′ 9″	Max. height
9	1/½″ thick:—Single concrete shell	10′ 9″	Max. height
10-11	Corrugated A.C. sheets, gypsum board ceiling from July to Feb. 1956	9′ 1½″	Average height
R-A	6″ thick:—2″ brick tiles on wooden rafters with 4″ mud phuska	8′ 10″	
51	9″ thick: —3″ Stone slabs with 6″ lime concrete using rubble stone aggregate	9′ 0″	
45	2½″ thick :—Precast R.C.C. slab on strest beams, top bitumen washed with mourrum sprinkled over it	10′ 2″	
46	4½″ thick : R.C.C. slab	10′ 3″	
48	5½″ thick:—3½″ lime concrete using brick ballast aggregate in between two 1″ Kotah stone slabs on top and bottom supported on wooden rafters	9′ 11″	
12	12″ thick:—R.C.C. beams with brick filling followed by lime concrete using brick ballast with bitumen wash over it	9′ 2″	
13	6″ thick:—2″ precast R.C.C. slabs on R.C.C. T-beams with 1½″ concrete with brick flats on top	8′ 8″	
14	11½″ thick:— 4½″ R.C.C. slab with brick flats in cement morter on top and mud in between	8′ 4″	
22	7½″ thick:— 4½″ brick jack arch with lime concrete using brick ballast aggregate in haunches & 3″ over the crown and topped with mourrum	9′ 11″ 9′ 7″	
23	6″ thick:—2″ precast cement concrete tiles over R.C.C. beams bitumen washed on top with 4″ mud phuska.	10′ 4″	
24	10″ thick:—Brick arch	9′ 9″ 8′ 3″	
26	6″ thick:—Archad and sloping roof Goona tile roof in lime mortar, with lime plaster on both sides	11′ 6″ 7′ 7″	
27	Corrugated A.C. sheet with gypsum plaster underneath	10′ 0″	
29	Corrugated A.C. sheets with gypsum plaster underneath	12′ 9″	Average height
30	6½″ thick:—3″ R.C.C. slabs with mud on top	10′ 0″	
53	1½″ thick :— Precast vacuum concrete shell	10′ 2″ 7′ 6″	
54	6″ thick:—4″ foamed concrete slab over pre-stressed concrete beams and mud phuska on top	9′ 9″	
41	4½″ thick:—R.C.C. slab	9′ 4″	
42	7½″ thick:—4½″ thick R.C.C. slabs with brick on flats on top	10′ 3″	
43	7″ thick :—2″ Precast R.C.C. tiles over R.C.C. beams with 3″ lime concrete using brick ballast aggregate and mud phuska on top	11′ 9″	
44	Curved A.C. sheets with 2″ air-gap in between	8′ 6″	Average height
65-66	Compressed bamboo mat boards and wood chip boards with hard board ceiling.	12′ 6″	

House No.	Specifications of roof	Height of ceiling	Remarks
33	4″ thick: – R.C.C. slabs	10″ 4″	
36	Thatch grass over bamboo trusses and purlins with timber plank ceiling	10′ 0″	
37	8½″ thick :— 4½″ R.C.C. slabs with 3½″ lime concrete and cement plaster on top	10′ 2″	
38	Manglore tiles, hip and valley roof on wooden rafters	10′ 7½″	Average height
40	7½″ thick:— 4½″ R.C.C. slabs with brick flats on top	10′ 1″	
55	1½″ thick :— synthetic wood panels	9′ 0″	
57	8″thick:—4½″ R.B. with brick flats on top	10′ 2″	
59	A.c sheet roof topped over with 1½″ thick mixture of road tar, sand, and saw dust in the ratio of 2:2:1	10′ 3″	
60	A.C. sheet over R.C.C. roof trusses, and purlins with ceiling of hession, rabit wire mesh sprayed with aerocem mixture	10′ 7½″	Average height
49-50	A.c. sheet roof with hard board ceiling	15′ 6″	Average height
34	G.I. sheet with chatai sheet	10′ 7½″	Average height
35	Creosoted shingle roofing on collar trusses	10′ 1½″	

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PART B

COMFORT SURVEY PROJECT REPORT

An investigation into indoor climate in houses put up for International Exhibition on Low Cost Housing in Delhi in 1954

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REPORT

ON THE

COMFORT SURVEY PROJECT

BY

B. C. RAYCHAUDHURI,
Scientific Officer,
Central Building Research Institute,
ROORKEE (U.P.)

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COUNCIL OF SCIENTIFIC AND INDUSTRIAL RESEARCH
NEW DELHI

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REPORT ON

Comfort Survey Project

1955-56

Synopsis

Investigations on the thermal behaviour, ventilation, illumination and dampness penetration, have been carried out on forty full scale houses at the Housing Exhibition Site, Mathura Road, New Delhi. Data for the period April 1955 to March 1956 are recorded.

A thermal behaviour chart for different types of structures is presented. The use of certain colour washes on external surfaces of the buildings, the necessity of specifying the location of windows in addition to the window area for ventilation requirements and the causes of dampness penetration are discussed in Section—I. The effect of ceiling height on indoor comfort is discussed in the Section—II.

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SECTION—I

Introduction

In order to arrive at a comparative assessment of the performance efficiency of the full scale houses at the Exhibition Site, investigations have been conducted by the Central Building Research Institute, Roorkee in collaboration with the Ministry of Works, Housing and Supply, New Delhi. Some forty houses were selected for study. A site plan of the houses is given in *Fig.* I. Brief specifications of these houses describing the roofs and walls and orientation are given in *Table* I. Areas of ventilation openings both closeable and permanent, together with window area and their locations are given in *Table* II. The investigations included (a) thermal and ventilation conditions; (b) daylight illumination; and (c) dampness penetration.

The results and discussions are based on experiments carried during the period April, 1955 to March, 1956. It would have been desirable to make definite recommendations as a result of this study, but this was not possible as the houses and their layouts were not designed specifically for such an experimental study, and a great number of uncontrollable variables have affected their behaviour. However, tentative recommendations on the basis of data for one year are presented.

Analysis has been made on a seasonal basis and day to day weather fluctuations have not been taken into account. The year has been sub-divided into three periods: April to June termed as dry summer, July to October termed as wet summer and November to March termed as winter. Details of weather conditions in Delhi during April, 1955 to March, 1956 are given in *Figs.* II—V.

This study is of interest, since individual factors *viz.* building materials, techniques of construction and design features are not independent variables as in laboratory studies, but are the components of full-scale houses, each contributing its share towards the performance of the house.

Design Requirements

A dwelling is primarily required for protection against the vagaries of weather and its requirements for efficient functioning are, therefore, different in different climatic regions. The climate in India can be broadly classified into two zones: hot-dry and hot-humid. Heat being a common factor in both the regions, the thermal performance of dwellings demands special attention. The design requirements of a dwelling in these two regions from the indoor comfort point of view are different. The dry climate raises the problem of high day time temperatures and dust storms, while the humid climate raises the problem of oppressive high humidity. In dry climates the aim of the design of the dwelling should be such that the outdoor heat reaches the inside only after night has set in and the outside is cooler. There should also be some arrangement by which with the advent of night the inner surface temperature can be brought down to air temperature.

In humid areas, the thermal stress due to high humidity should be tackled by thorough ventilation.

Heat being a common factor, the reduction of insolation by proper shading and surface treatments and the advantage of good ceiling insulation are common to both regions. Adequate ventilation is also necessary in dry climates during the sticky monsoon months.

In short, the heat capacity of materials is the dominating factor for dry climates while the provision of thorough indoor ventilation conditions is the important factor dictating the design in humid climates.

Some other important problems in connection with efficient functioning of a dwelling are enumerated below. Glare and day lighting are important factors demanding the attention of the designer. In certain rooms of a dwelling such as kitchen the problem of day lighting should receive attention. The weathering of building materials and penetration of dampness are important because of the extremes of climate and heavy rains in certain regions. The provision of outdoor night sleeping space in regions where the nights are hot, the distribution of rooms and designing of layouts from the point of view of causing minimum fatigue to the housewife etc., also demand the attention of the designer.

Work done Abroad

Investigations on the thermal behaviour of dwellings on full scale test huts and dwellings have been carried out in Australia, South Africa, Israel, U.S.A. and also recently at Kuwait by the Building Research Station, England.

In Australia, the Commonwealth Experimental Building Station, Sydney, started a long term project in 1947 and continued it upto 1952. An extensive indoor temperature survey was undertaken in existing dwellings, and experimental huts in different climatic zones; and also one full scale, one quarter scale and one ninth scale thermal models constructed within the Institute premises. The models were of various designs, using different materials of construction, roof ceiling combination, surface finishes, roof space ventilation etc. Ultimately a bulletin on the "Designing of Houses for

Australian Climates" was published recommending certain principles to be observed in different climatic zones of Australia with regard to the design of walls, partitions, roofs, ceilings, floors, windows, internal doors, shading, insulation and surface treatment etc.

In South Africa, the National Building Research Institute carried out experiments on the heat transmission characteristics of different types of roofs, walls and roof-ceiling combination under periodic heat flow in a test room with detachable components. Later this work was suspended and series of extensive investigations were conducted for several years on fifteen experimental houses which were kept unoccupied during the entire period. The object of these full scale experiments was to ascertain the exact nature of the thermal conditions which prevail in the interiors of various types of thin low cost houses at different times of the day, different seasons of the year and under a variety of weather conditions, and with the aid of this data to define the design and specifications limit of low cost houses, so that there would be no deleterious effects on the health and well being of the occupants.

In Israel, work has been done on test huts with a view to determining the thermal behaviour of various roofs and walls.

The Building Research Station, England has recently conducted a project on the thermal behaviour of model structures at kuwait. This project was concerned with the mechanism of heat flow rather than with indoor environment.

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Similar work has been done at Austin, Texas, U.S.A., and by the Division of Building Research, Canada at Saskatoon.

In addition, the mathematical approach to the thermal behaviour of dwelling and the analogy methods of solving problems of heat transfer through building components has received attention in U.K., U.S.A. and Australia.

Thermal Investigations

The indoor ambient air temperature is the result of the combined effects of the design features and the building materials used, while the difference of interior and the exterior surface temperatures of the walls and roofs shows the behaviour of the walls and the roof materials against the inward flow of heat. In hot dry areas, during summer, windows etc. are usually kept closed during the day and the extent of direct entry of air-borne heat is small. Therefore, the indoor air temperature and the interior heat gain are governed by the room surface temperatures.

In the design of a dwelling in the tropics where mechanical aids such as coolers are not generally used, the rate of heat penetration through the structures and the extent to which the external diurnal range of temperature is damped are more important than the amount of heat transfer through the structure.

While the amount of heat transfer is dependent on the thermal conductivity of the materials (K), the rate of heat penetration and the decay in amplitude depend on a factor termed thermal diffusivity (h^2). These two are related to each other by the equation:

$$h^2 = K/pc,$$

Where,

K = Thermal conductivity, Btu/ft^2 /hr/°F/in.
p = Density . . . lbs/ft^3.
c = Specific heat . . Btu/lb/°F.

In considering walls or roofs it may be assumed that the temperature wave has been imposed on one side of a slab of homogenous material, the other side of which is protected from the direct effects of the temperature wave. It is also reasonable to assume that the temperature wave is a sinusoidal one. The material through which the temperature wave is passing will cause a decay in the amplitude of the wave and also introduce a time lag.

It has been shown that:—

$$V = 2(h^2\pi/T)^{\frac{1}{2}}$$

and $$\frac{\theta i}{\theta} = e^{-L(\pi/h^2T)^{\frac{1}{2}}}$$

Where V = rate of heat flow or velocity factor in ft. per hour.
T = time period (in case of diurnal range, 24 hrs).
L = thickness of the materials, in feet.
θi = amplitude of internal temperature variation, in °F.
θ = amplitude of external temperature variation °F

From the above it follows that low values of thermal diffusivity produce a greater decay in temperature amplitude and a slower heat penetration rate, and are therefore desirable. The thermal efficiency of the slab will be determined by the extent to which the temperature wave has been damped. This damping can be measured as:—

$$\text{Thermal Damping} = \left(1 - \frac{\theta i}{\theta o}\right) \times 100$$

The importance of the thermal diffusivity will be clear from the following example. It has been reported that while concrete (150 pcf) and tightly packed earth (with 24%mc) have the same thermal conductivity of 0·8330 Btu/ft/h/°F., the thermal diffusivity and the velocity factor in the case of concrete are 0·023 ft^2/hr. and 0·115 ft/hr whereas those for earth are 0·018 ft^2/hr and 0·097 ft./hr. Hence for thermal comfort tightly packed earth is better than concrete although both have the same thermal conductivity.

It has also been noted that two walls with similar thermal transmittance figures but of dissimilar diffusivity values have given different results. The internal surface temperature maxima was higher for the wall with the higher diffusivity value.

These considerations may also be applied to the house as a whole, assuming the house to be a closed box with the inside protected from direct outside effects. In general practice, the conditions in a house are not as ideal as those of a closed box because of ventilation and solar radiation through windows, but for practical purposes thermal damping can be taken as a measure of the thermal efficiency of an unventilated house and also of its walls and roofs. The depression in maxima, *i.e.* the difference in outdoor and indoor maximum temperature, is another indication of the thermal behaviour of the house as well as of the roofs and walls.

From the above formula it can be seen that the thermal damping and the depression in maxima are inter-related, so that the more the damping the more is the depression.

The thermal damping of roofs and walls are properties of their materials irrespective of the surface finishes and orientation. If the actual surface temperatures are considered these are dependent on the surface finishes and orientation.

Experimental

Temperature measurements were taken in the living room of the house—the indoor ambient air temperature at 5 ft. above the floor level and in the middle of the room, the inner and outer surface temperatures at the centre of the roofs and of some characteristic walls with worst exposure at 5 ft. above the floor height and at the centre, were recorded with the help of thermocouples. The outdoor shade air temperatures were recorded with autographic instruments in the Stevenson Screen at a Standard Meteorological Enclosure at the site. In addition the outdoor shade temperatures also were taken with a thermocouple placed in the Stevenson Screen. The leads of all surface and air thermocouples were brought to a precision portable potentiometer through a battery of selector switches. The observations were taken hourly by manual operation and readings plotted, and the temperature peaks determined after smoothening the curves where necessary.

Results and Discussion

The average monthly values of thermal damping for the roofs, walls and houses are presented in *Tables* III, IV *and* V respectively The data for depression in maxima are also presented. The data are for two conditions of exposure, viz. (i) windows and ventilators closed for 24 hours and (ii) windows and ventilators closed during the day and opened at night. The data for average maximum temperature for each month are presented in *Table* VI. Data on rainy days have not been taken into account. The average seasonal values of thermal damping and depression in Maxima for roofs, walls and houses have been presented in *Tables* VII, VIII and IX and the discussions which follow are on the basis of the seasonal values. The walls and roofs will be considered first and then the houses as a whole. Clearly the less the amplitude of the temperature indoors compared with the amplitude outside, the better thermally will be the wall, the roof or the room. It is proposed accordingly to accept arbitrarily a damping factor of 65% or greater as indicating thermally satisfactory performance.

Roofs (Tables VII)

There are 19 cement concrete roofs, eight brick roofs, two stone roofs, seven A.C. sheet roofs, one G.I. sheet roof and three roofs made of wood or bamboo panels and one of thatched grass.

The results show that the thermal damping has followed more or less closely the thickness of the roof. In usual cases a thickness of 6 inches and above has given a thermal damping of more than 60%. A thickness of more than 7 in. has given a factor of more than 66%.

For cement concrete roofs a thickness of 4½ inches (No. 41) has not proved satisfactory. Much improvement is, however, effected by the addition of a layer of 3 in. to 4 in. of lime concrete, mud or brick flats. The best amongst the concrete roofs are (No. 2) a 6 in. R.C. slab with brick flats and (No. 14) a 4½ in. R.C. slab with 4 in. mud and flat bricks. The 1½ in. concrete shells have proved to be thermally very poor roofs (Nos. 53 and 9).

It can be seen that wherever mud phuska has been used in conjunction with R.C.C. the damping factor is much better than when an equivalent thickness of cement concrete is used. This is due to the fact that the diffusivity of mud phuska is lower than that of concrete.

The foamed concrete roof (No. 54) has behaved well. This would seem contrary to the common belief that the damping factor increases as the mass of the structure is increased. The damping factor is dependent on diffusivity i.e. the thermal conductivity divided by thermal capacity. Usually the reduction in conductivity is associated with the reduction in density. But in the light weight concrete, if the reduction in conductivity is more effective than the corresponding reduction in capacity, the diffusivity will decrease and hence the damping factor will increase. The work regarding the determination of diffusivity, conductivity and capacity of building materials and their mutual variability opens up an interesting field of work.

The roofs of No. 6 and No. 8 appear similar; but No. 6 has behaved better than No. 8. This is due to the fact that the ventilation condition between the two skins in No. 6 is much better than that in No. 8 and this better ventilation is responsible for the better behaviour of roof No. 6.

The brick roofs, on the whole, have given satisfactory results. Precast beams with brick filling and lime concrete above have produced the best roof (No. 12). A roof (No. 38) with Mangalore tiles has not proved satisfactory.

The reinforced brick work with mud phuska gives a much better performance than dense concrete with mud phuska. This is due to the fact that the diffusivity in the case of brick work is less than that of concrete.

Stone roofs have not proved satisfactory (No. 48, 51) due to their high thermal diffusivity.

A.C. sheet roofs have proved unsatisfactory except in two cases, one with double layers and with 2 in. air gap in between (No. 44) and the other with a false ceiling of *hessian* on *rabbit wire mesh* and sprayed with *aerocem* mixture (No. 60). There was a considerable improvement to an A.C. sheet roof when a *cellotax* lining was added with a 6 in. air gap between it and the roof (No. 10-11).

If the roofs of No. 10-11 and No. 3 are compared, the values for No. 3 would be found higher. This is most probably due to the fact that there existed copious ventilation conditions just under the roof in the case of No. 3 and not in the case of No. 10-11.

Although the mass of the roof in House 44 is very low, it has shown a good performance by giving damping and depression values. This is due to the fact that the surface of the asbestos sheets being white, a good amount of sun's radiation was reflected from the exposed surface of the upper skin. This has grown hot by absorption of the remaining amount of sun's radiations and has become a source of secondary radiation. The upper surface of the inner skin also being white has reflected away a considerable amount of this secondary radiation. In addition, conditions of copious ventilation existed in between the two skins which helped to take away some of the heat from the cavity. This, however, requires further investigation.

A thatched roof with timber false ceiling (No. 36) and a compressed bamboo mat board roof with a hard board false ceiling (No. 65) have thermally behaved well, but roofs with synthetic wood panels (No. 55) have not.

The thermal behaviour of a G.I. sheet roof with chatai ceiling (No. 34), of an A.C. sheet roof with a *celotax* ceiling (No. 10-11) and of an A.C. sheet roof with a ceiling of *hessian* sprayed with *aerocem* (No. 60) are similar.

In short, a roof of built-up thickness of 6½ in. or more consisting of R.C.C. or brick masonry with or without mud phuska and lime concrete have generally proved to be good from the thermal point of view. Asbestos roof and G.I. sheet roof with false ceiling of insulating material have also proved to be good.

Walls (Table VIII)

The walls are mostly 9 in. brick in mud or cement mortar, with ½ in. sand cement or lime plaster on both sides. There are a few 14½ in. brick walls.

Other types are hollow blocks of gypsum, cement-cinder concrete and cavity walls of brick masonry.

Based on theoretical consideration the heat penetration, through a typical masonry, is as follows:

It is seen from *Fig.* VI that the amplitude of the temperature wave decays considerably after its penetration through 9 in. of masonry and there is little further decay as it penetrates further. The decay is less than 3 percent of the surface amplitude when it has penetrated 12 in. of masonry. The experimental observations of Prof. Thoburn, corresponds roughly with the above.

It is observed that a 14½ in. brick wall is better than a 10 in. brick wall. The 8 in. concrete, gypsum or cinder concrete hollow block walls give less satisfactory performances. The cement concrete hollow block wall was improved to some extent by opening the cavity at night thereby introducing natural ventilation in the cavity. The gypsum and cinder concrete hollow blocks have behaved thermally better than ordinary cement concrete hollow block walls. The 14½ in. brick cavity wall has given the best performance and when the cavity was ventilated, there was further improvement.

One point of interest may be discussed here. A comparison of walls of different orientation, with different amounts of irradiation may not seem justified. But their thermal damping values are comparable. This factor is derived as a ratio of the range of inner and outer surface temperatures. Hence, the factor of orientation, the external finishes and shading by trees should not effect the differential, although these will effect the actual surface temperatures. However, a solar chart for Delhi with shadow angle protractor is included from which the angle of incidence of solar radiation and hours of irradiation could be found out (*Fig. VII*).

To make it clear a comparison is made between two similar walls (Nos. 3 & 33). No. 3 has higher damping and depression values. The wall of No. 3 faces South-East, while the wall of No. 33 faces North. The internal surface temperature of No. 3 is more than that of No. 33 even though it has more damping and depression values. This is because of more irradiation on the wall of No. 3. If, therefore, damping values are considered, these would be independent of orientation, irradiation etc.; but when the actual temperatures are considered, these will depend on the exposure factor and surface finishes.

The indoor surface temperature of wall of No. 10-11 is more than that of No. 12 but the wall of No. 10-11 has higher damping and higher depression values than those of No. 12. This is due to the fact that the external face of No. 10-11 is pointed and has a red facing, while No. 12 has a plaster on it with a light yellow wash. From the temperature point of view, the wall of No. 12 is better than that of No. 10-11; but the comparison is not permissible on temperature factors due to the difference in exposure and surface conditions. However, the thermal damping values are independent of the factors of exposure and surface finishes. As such, this gives a more reliable assessment of the thermal behaviour of materials used, and is more amenable to useful generalization for future constructions where orientation and surface finishes could be easily changed without effecting the cost in an appreciable way. Hence, from these considerations the wall of No. 10-11 is better than that of No. 12.

A further critical study of the data on walls will elucidate the above point conclusively.

House (Table IX)

Observations were made only in the living rooms and the performance of the house as a whole was judged on the basis of their behaviour.

Some of the houses were designed for hot-humid areas and others were designed for hot-dry areas. Since it is not intended to compare their livability but only their thermal performance, a comparison is permissible between the two types.

House No. 4 behaved much better than No. 5 in spite of the fact that the former was directly exposed to the sun and the latter was shaded by a wide verandah. Both have similar walls but the roof of

No. 4 is better than that of No. 5. The thermal performance of the roof was one of the main causes for this better performance. Similarly house No. 2, in spite of its South-West orientation, behaved well. The better performance was due to the fact that it had a better roof. This leads to the conclusion that the effect of bad orientation can be compensated by a better roof.

House No. 12 and No. 14 have shown similar thermal behaviour. They have walls of different thickness, but their roofs have more or less similar thermal performances. This tends to confirm the fact that the roof is the most important competent of a room and greatly influences its performance.

House Nos. 5 and 6 behaved differently although the roof behaviour of both were roughly the same. This was due to the fact that a greater surface area of the house No. 6 was exposed to the sun.

The roof of House No. 26 was good. But the house did not behave well thermally during summer. This may be attributed to the large jally typed permanent ventilators at window level which have offset the stabilising effect of the high capacity structure. During winter, these permanent ventilators were sealed off altogether and much improvement was noticed in the house behaviour.

The thermal performance of the roofs of house Nos. 24, 40 and 44 were good. The house behaviour on the other hand was not good in summer probably because there were permanent ventilators in each house. During winter, when permanent ventilators were sealed off together, there was a corresponding improvement in the thermal behaviour in each of the houses.

Effect of Windows Opening

If windows are kept open during the night and closed during daytime, houses are expected to cool down earlier and to a greater extent. The carry over of the nights cold tends to delay the arrival of the indoor maxima and helps to keep the structure cooler on the following day.

It is seen from the data that the damping values for walls, roofs, and houses have decreased in most of the cases. both during summer and winter. The decrease of damping means the corresponding increase of the indoor range of temperature. The data shows that there is a significant lowering of indoor minima. There should also be some lowering of indoor maxima due to the carry over of night's cold, which would be indicated by the increase of the depression in maxima. It is seen from the data that during summer there is an increase of depression in maxima in 14 per cent. of roofs, 68 per cent. of walls and 26 per cent. of houses.

This anomaly may be due to the opening of windows between 6 and 7 p. m. and closing them between 8 and 9 a. m. resulting in direct entry of the sun for about three hours in the morning and thus heating of the inside surfaces. This is clear from a critical study of the location of openings. Later on during winter, the windows were opened after sunset and were closed before sunrise. It is seen from the winter values that most of the roofs show an increased depression in maxima and there is an increase in 50% of walls only. There is still a decrease of depression in maxima in almost all the houses. It will be seen later that there is a relationship between the outdoor maximum temperature and the depression in maxima (Thermal Behaviour Chart).

The permanent ventilators were also closed altogether from September. It was found that the damping and depression for houses have increased considerably both for ventilated and unventilated conditions. The indoor maxima temperatures were also maintained much lower when the permanent ventilators were closed altogether.

Seasonal Variation

It is seen that there is not much variation from season to season in most of the roof slabs and walls. Some variations are, however, noticed in the houses.

The thermal damping being a property of the materials should not vary, for practical considerations, due to seasonal temperature variation. But the structure contains a good deal of moisture in it, the amount of which changes from season to season. The amount of moisture present in the structure is maximum during wet summer and minimum during dry summer, the conditions during winter being in between. Due to the presence of moisture the diffusivity is expected to increase and hence damping should be decreased with the presence of more moisture.

It is seen that for most of the roofs in both ventilated and unventilated conditions of exposure, the thermal damping decreases in wet summer and again increases in winter; the winter values being less than that of dry summer. The depression of maxima also shows a similar behaviour.

A similar behaviour is noticed in 50 per cent of the walls only. The number of walls showing similar behaviour is more in unventilated conditions of exposure.

The houses, on the other hand, has shown a regular increase in the damping values from dry summer to wet summer and then to the winter in both the ventilated and unventilated conditions of exposure. In 50 per cent cases, there is a decrease in depression from dry summer to wet summer and then again in winter. It should be noted that the permanent ventilators were sealed off altogether, during winter.

Temperature curves for two houses, Nos. 12 and 22 are presented in *Figs.* VIII and IX to show the growth and decay of temperatures of the outdoor air, indoor air, the exposed and the under-side of the roof, the internal and external wall surfaces.

Thermal Behaviour Chart

The depressions in maxima, for four houses of different weights of construction, were plotted against the outdoor shade maximum temperature (*Fig. X*). It showed that for those buildings which were of more or less traditional construction, there existed a relationship between the weight of construction and the depression in maxima. From this graph, a prediction of indoor temperature conditions of these or similar types of houses, in different shade maxima, is possible.

The shade maximum temperatures of different places (hot-dry) could be analysed and design temperature might be drawn up from frequency analysis. This type of graph could be used while building similar types of houses, keeping in view both the factors of temperature drop and economics.

Effect of Surface Treatment

In order to evaluate the effect of surface treatments, the exposed surfaces of two roofs were white washed. One house was kept unventilated and night ventilation was introduced into the other. The data is presented in *Table* X. It is seen from the table that the thermal damping values for roofs with or without surface treatments are more or less similar. But the ceiling temperature was lessened by eight degrees in one case and by four degrees in another after white washing. This shows the benefit of white washing the exposed surfaces of the roofs, in bringing down ceiling temperatures. It is usual to keep a master for strict comparison in these types of studies, but this was not done as one was not available.

Effect of Modifications

A house (No. 10-11) with 14½ in. brick cavity wall and A.C. sheet sloping roofs showed unsatisfactory behaviour. The roof was considered to be the cause of this. Some modifications, such as the incorporation of a false ceiling, ventilation of roof space etc., were tried. The data are presented in *Table* XI. It is seen from the table that the thermal behaviour of the roof and the house was improved to a considerable extent by a false ceiling of celotex or gypsum board. The wall performance was improved by ventilating the cavity. The roof space was ventilated for 24 hours but this did not make any marked change, possibly because the ventilation was slight due to small openings. Night ventilation has reduced the damping values but the depression values did not suffer much change except for the house.

If a comparison is made between celotex and gypsum board as ceiling material, both show a more or less similar thermal behaviour.

It is seen that the A.C. roof has behaved satisfactorily with the incorporation of a false ceiling. If at night, the false ceiling is removed the house loses the day stored heat through the thin roof easily and the house behaves much better. This was tried and it was seen that the damping values were decreased in all the cases indicating the attainment of lower minimum temperatures. The depression values were increased for roofs and walls but decreased in the case of the house.

This shows that the incorporation of an insulating false ceiling to the asbestos roof, improves the thermal behaviour of a house considerably. Introducing night ventilation during summer adds to the improvement. The removing of false ceiling during summer nights and putting the same back during the day, although not practicable at present, introduces further improvement.

Rates of Cooling

The cooling of buildings during the night is also an important aspect as far as the thermal performance of dwellings is concerned.

The average rates of fall of the indoor air temperature, the ceiling temperature and the temperature of the internal surface of walls for four houses together with the rate of fall of outdoor temperature is presented in *Table* XII.

The rate is calculated from the temperature range divided by the number of hours between the two peaks.

It is seen that the rates of fall of the indoor air temperature and of the internal surface temperatures of the ceiling and of the walls in each house are of the same order, all lowest in one house and highest in another. House No. 12 having thicker roof and walls has the least rates of cooling, whereas, No. 33 with thinner roof and walls has the highest rate. No. 5 and No. 22 have similar walls but the roof of No. 22 is thicker than that of No. 5. Hence, House No. 22 has a lesser rate of cooling than No. 5.

By introducing night ventilation the rates of cooling are, as might be expected, much increased.

The rate of fall of outdoor temperature has also an effect on the indoor rate of cooling. Graphs have been plotted for the indoor rate of cooling against the outdoor rate. These are presented in *Fig.* XI.

It is seen that the indoor cooling rate increases with the increase in outdoor rate of cooling. The increase is much more for No. 5 than for No. 12. For the same house, again, the curve is steeper for ventilated than for unventilated conditions. The rate of fall of ceiling temperature is higher than that of indoor air, especially for thin roofs.

Conclusions.

The following conclusions of a general nature have emerged from the thermal study:—

(1) Heat capacity plays an important role in regulating the thermal performance of buildings, especially in hot-arid zones.

(2) Where artificial cooling aids are not used it is the thermal diffusivity of the materials which is more important than the thermal conductivity.

(3) If windows are kept closed during sun up hours and open during sun down hours, there is an improvement in the behaviour of houses in summer.

(4) The presence of large permanently open ventilators offset the advantages of high heat capacity structure in dry areas.

(5) As far as thermal comfort is concerned the roof is the most important component of a building.

(6) If it is not possible to orient a building to the best advantages this can be compensated for, by providing a better roof.

(7) A roof of built up thickness of 6½ in. or more consisting of R.C.C. or brick masonry with or without mud--phuska, lime concrete etc. gives satisfactory results from a thermal point of view. Brick roofs are thermally better than concrete roofs of similar thickness and mud phuska is better than the lime concrete for roof insulation. 4½ in. cement concrete roofs, thin stone roofs and bamboo roofs are not satisfactory. A. C. sheet roofing, tiled roofing and corrugated G.I. sheet roofing alone are not satisfactory, but the addition of a false ceiling makes a considerable improvement.

(8) Ceiling temperatures can be brought down to a considerable extent by white washing the exposed surfaces of the roofs.

(9) 9 in brick walls with plaster on both sides are thermally satisfactory; 13 in. brick walls and 14 in. hollow brick walls are still better.

(10) 4½″ brick, 8″ concrete hollow block and 8″ gypsum hollow block walls are thermally not very satisfactory.

Thermal Properties of the Surfaces

Protection against insolation implies that the external surfaces of walls and roofs reflect the maximum amount of the Sun's radiation. Measurements were carried out for several wall surfaces with a precision exposure photometer. The brightness of wall surface at a point was first measured and then the brightness of a standard white surface placed in the same position. The ratio in percentage is termed the reflection co-efficient. Measurements were carried out at five differnt points on the same surface during winter. The values are presented in *Table* XIII.

According to the recommendations of the Environmental Hygiene Committee of the Ministry of Health, Government of India, the reflection coefficients of the external wall surfaces should not be less than 65 per cent. It is seen from the table that surfaces with white, cream and light yellow colour washes satisfy these requirements while brick, cement, mud and red washes do not.

It is seen from the data that the reflection coefficient values are less on a cloudy day in 65 per cent of the cases, indicating the reflection is more for higher radiation intensity.

Use of deep red colour washes at the external surfaces of buildings is of late, being practised for architectural effect. While the house beautiful move is commendable, the fact that deep red coloured surfaces have very poor reflection coefficients should not be lost sight of.

It is seen that, since brick surface has a poor reflection coefficient, the provision of plaster which is normally white or colour washed, would improve thermal behaviour. In addition this plaster acts as an effective barrier to dampness penetration and protects the bricks from weathering.

Ventilation

Even in a hot-dry region, effective ventilation is an important factor. A certain minimum rate of air change is required for health reasons and a reasonable amount of uniformly distributed air movement is required for comfort, especially in the monsoon seasons. Both these factors, depend upon the area and location of openings provided in a house, together with its orientation in relation to the mean monsoon wind direction.

It would have been desirable to study the relation of the window areas with the air movement inside expressed as the ratio of the air movement outside. However, this could not be done because the windows were located at various heights and in different positions in the rooms. Nevertheless, an attempt has been made to outline a few broad guiding principles for the location of windows.

The air movement was determined inside as well as outside for each house during the afternoons of September, 1955. For inside measurements, doors were kept closed but all other openings were kept open. An unsilvered low range (95-100°F) Kata thermometer was used for determining the cooling time and a whirling Psychrometer for the corresponding dry bulb air temperature. From these two and the known factor of the Kata thermometer, the air movement in feet per minute was calculated.

The ratio of inside to outside air movements, expressed as a percentage, is termed the effective ventilation. The wind direction was noted at half hourly intervals during the period of observation. The values of effective ventilation for two calm days with light air movement from East and South East are given in *Table* XIV.

Discussion

House Nos. 27 and 29 facing South-East have nearly equal percentages of window area. But the former has two windows each on the opposite walls and the latter has only one wnidow. The effective ventilation is 57·7 and 25·9 respectively for the wind direction East and 21·6 and 11·4 for the wind direction South-East. This shows that if the same window area is distributed to allow for cross ventilation, the effective ventilation increases considerably.

Windows need not be on opposite walls. In house No. 5 where windows are in the adjacent walls, with wind direction East, these windows served the purpose of cross ventilation and effective ventilation was 51·2. It was reduced to 22·1 for wind direction South-East. The distribution of windows should be planned not necessarily on opposite walls but with a view to providing cross ventilation by placing them along the mean wind direction for the monsoon season.

In House No. 6 with wind direction East, the ventilation was 100. This is probably because the direction of air flow through the windows of South-East wall and window on the further end of North-West wall, passes near to the point of observation at the middle of the room.

Conclusions

1. Openings should be provided on two walls, which need not always be opposite walls.

2. If windows are provided only on one wall, one wide window or two windows at the corners should be preferred to one narrow window in the middle.

3. Windows should be located so that the line joining their mid-points is almost parallel to the mean monsoon wind direction.

4. To get a uniform distribution inside the room and to avoid air locks at the corners, windows' location should be such that the direction of air flow passes nearest to the middle of the room. This consideration may imply in some cases, a reduction in the effective available opening, thereby reducing the actual amount of air movement. In such cases the window areas are to be increased to get sufficient effective opening.

5. While fixing the relative dimension of windows of a given area, it should be borne in mind that effective ventilation depends on the total width.

6. It is not sufficient to prescribe a window area as a ratio of floor area. The distribution and location of windows are also important and should be given due consideration.

Day Light Illumination

In India, there is plenty of sunshine and the problem of day-light indoor illumination is not important except for some areas in winter. The ventilation openings provided for healthy indoor living are usually adequate for illumination. An investigation was, however, conducted to find out the actual daylight illumination conditions indoors in various designs and layouts of houses.

Measurements were made with a precision Exposure Photometer. Brightness of a standard white surface placed on the floor in the middle was measured followed by the measurement of the sky brightness as seen through the most exposed windows. The windows were kept open during the period of observation. The observations were taken at mid noon when the sun was at the zenith thus avoiding direct sunshine indoors and getting only the effect of sky brightness. The ratio of inside illumination to that of the sky expressed as a percentage, is termed the "Effective Illumination". Measurements were carried out previously at one point only at the middle of the room and on the floor. Subsequently, measurements were carried out on five different points, equally spaced inside the room and at 33 in above the floor level. The observations are presented in *Table* XV.

A correlation of the window areas with the effective illumination inside is not possible because windows have widely varying orientation and exposures and are located at different heights. Nevertheless an attempt was made to make an overall assessment on a comparative basis and to draw a few general deductions therefrom

Discussions

The Environmental Hygiene Committee, Ministry of Health, Government of India has recommended that the window designs should be such that the daylight factor should exceed one per cent. over half the floor area. The daylight factor, according to the definition of the International Commission on Illumination, is the vertical component of light falling upon an indoor plane, 33 in. above floor level, expressed as a percentage of the vertical component of the daylight which would have been received if the whole sky was visible, the sky being considered as a hemisphere of uniform brightness of 500 foot-lamberts.

Effective illumination values are presented in the *Table* XVI for a clear day in spring, summer, winter and also for a cloudy day in summer, autumn and winter.

It can be seen that the winter observations being recorded at 33 in. height are much higher than those of spring, summer, and autumn. During winter it ranged between 1 and 5 whereas in previous cases it was between 1 and 3.

Windows of Nos. 2 and 3 have the same location, but No. 2 has a larger window area. However, the effective illumination in both cases is nearly equal. This is attributed to the better exposure for No. 3.

In the case of House Nos. 9, 10-11, Rural A, and 51, the window locations are the same and the window area is maximum with No. 51 and minimum with Rural A. The effective illumination is also maximum at No. 51 and minimum at Rural A.

House Nos. 14, 22 and 23 having the same window areas have nearly equal effective illumination values.

It can also be seen that the clouds in autumn being of lower heights are much more effective in reducing the illumination indoors than the high clouds of the summer season.

Note: These observations for the air movement inside the room were taken at the middle of the room only. It is desirable that observations should be taken at five points inside the room to give a clearer picture of the distribution of the air movement.

Conclusions

In summer season, the openings required for ventilation purposes generally produce adequate illumination indoors.

Dampness Penetration

Observations on dampness penetration were carried out by visual examination and by touch. There was a continuous rainfall of 6·6 in. over a period of 28 hours, a day before the observation. Almost the entire rain was from the east and it directly beat against the walls of the houses. The external faces of the walls on the eastern side of the houses were, therefore, wet in most cases. Where the joints and corners have leaked, the walls were also damp internally. This may be due to the water coming directly through the cracks.

Observations are presented in Table XVI and are summarised below:—

(a) *Roofs and Floors.*

1. Houses with roofs having waterproof renderings have behaved well. In a few cases minor leaks were found at corner joints only.
2. Precast roofs leaked badly due to poor joints even when the roof was coated with a water-proof rendering.
3. A.C. sheet and G.I. sheet roofs have behaved well.
4. Floors with very low plinths were damp.

(b) *Walls.*

1. Cavity walls have proved to be damp-proof.
2. Hollow block walls have behaved well except in one case probably due to indifferent workmanship.
3. 4½″ thick walls of even good materials have leaked.
4. 9″ brick walls with plaster on both sides have not behaved bad.
5. "Aerated concrete" walls have proved to be damp-proof.
6. Agricultural waste material used for walls is extremely water absorbent.

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SECTION—II

Minimum Ceiling Heights

The problem of deciding what should be the minimum ceiling height in low cost dwelling houses is an important one. In cold countries like U.K., the municipal regulations require a minimum ceiling height of 7 ft. 6 in. or 8 ft. whereas in tropical countries the requirement ranges from 9 to 12 ft. Raising a room from 8 ft. to 12 ft. increases the wall areas by about 30 per cent which in turn involves more cost.

Although most people have a feeling that in tropical countries, a room with a high ceiling is much more comfortable especially in summer, there is lack of scientific data on the subject.

If the problem is approached scientifically, it will be seen that there are two main factors which determine the minimum ceiling height of a room *i.e.* adequate head room, and the health and comfort of the occupants.

Head Room

Adequate head room depends on artificial lighting fixtures and ceiling fans. The minimum hanging height of a ceiling fan being 18 inches, this fixes the minimum height of the ceiling at about 9 ft. There may be some doubt about the efficiency of ceiling fans when the hanging height is 18 inches. This requires to be confirmed by detailed analysis and experimentation.

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Health and Comfort

The influence a ceiling may have on health and comfort is due to its surface temperature or because its height may affect ventilation conditions.

Ceiling Temperature

A ceiling will radiate heat indoors only if it is hotter than the indoor air or wall temperatures. The surface temperature of a ceiling does not vary with its height. The ceiling temperature of a wall insulated roof may not differ very much from the indoor air or wall temperatures, whereas that of a thin and uninsulated roof may be considerably higher.

The intensity of the long wave radiation which is emitted by the hot ceiling decreases as it travels downwards due to absorption of this radiation by the moisture present in the air. This absorption is also proportional to the concentration of the moisture content in the air. The amount of this radiation which is received by the occupant depends on the thickness of air masses through which the ceiling radiation has to pass, the moisture concentration in the air, and the solid angle subtended by the occupant with the ceiling. Therefore, higher the ceiling, the lesser should be the radiation. Hence there should exist a vertical gradient of radiation intensity. It has been reported that in usual cases, no significant effect of ceiling radiation is felt beyond 3 to 4 ft.

The problem of the ceiling radiation arises only when it is hotter than the indoors. Therefore, where the ceiling temperature is higher than the indoor temperature it would be more effective and economical to bring down the ceiling temperatures by adopting such measures as colour treatment of the roof surfaces, shading and insulation than to raise the ceiling.

Ventilation

Natural ventilation is affected by wind forces and stack effect. The ceiling height does not affect natural ventilation due to wind forces. Ventilation due to stack effect, however, depends among other things, on the square root of the difference in height between inlet and outlet openings. Ceiling height will only affect the ventilation if these inlet and outlet openings are at the floor and ceiling levels respectively. In that case also, it has been reported by Atkinson that an increase in ceiling height from 8 ft. to 12 ft. would increase the rate of air supply by about 20 per cent for calm and closed condition. But doubling the size of openings would increase the rate by 100 per cent. For breezy and open conditions ceiling height is unimportant.

It has been suggested by various authorities that a supply of 600 cu. ft. of fresh air per person, per hour, is required from the point of view of health, and also to prevent odour concentrations. Crowdon has stated that natural ventilation requirements can easily be met in England without discomfort in fully occupied rooms of 7 ft. in height by appropriate use of hopper windows. As supply of fresh air is also required to lessen the indoor humidity which tends to rise as a result of the breathing and sweating of the occupants. Experiments on these lines should also be conducted in tropical countries.

There may be other considerations in deciding minimum ceiling heights:—

(a) Hot air and humid air being less dense have better chances of rising above the occupants' head level, if the ceiling is high. Therefore, in a room with high ceilings, the occupants will not feel the effect of hot air and the effect of increasing humidity due to perspiration and sweating. However, the use of a ceiling fan mixes up the air layers and this theory does not hold. A determination of the temperature and humidity gradient in an occupied room is worth examining.

(b) The roof of a tall building should be subject to more thorough overnight cooling due to its being high above the ground. Prof. Thoburn, however, states that the differences in overnight cooling at different levels are not great enough to be detected with certainty.

(c) 'Psychological effects' of which this study has not taken account.

Preliminary Experiments

Experiments on these lines were started at Roorkee on four similarly built, full scale, unoccupied rooms of 11ft. 6 in. by 9ft. 6 in. and with ceiling heights of 7 ft. 6 in., 9 ft., 10 ft. 6 in. and 12 ft. A short duration experiment was also conducted during June 1956 at the Housing Exhibition Site, New Delhi on four identical experimental unoccupied units of 12 ft. by 10 ft. and with ceiling heights of 8 ft., 9ft., 10 ft., and 11 ft.

Experimental

The indoor air temperatures were measured by placing thermographs at a height of 5 ft. from the floor in the middle of each room at New Delhi and at 3 ft. height in Roorkee. Outdoor temperatures were recorded by a thermograph in the Stevenson Screen fixed at the site at New Delhi. In Roorkee, however, the climatological data have been taken from the Institute's climatological observatory.

To measure the temperature gradients, Six's maxima-minima thermometers were attached at one foot intervals to a string fixed vertically in the middle of each room.

New Delhi Observations

The short term study at Delhi was planned to continue for a fortnight in three instalments of five days each, each pertaining to a different condition of exposure.

In the first condition the houses were closed completely and the glass panes shielded with celotex boards. In the second, night ventilation was introduced and the fan switched on between 0900 to 1700 hrs. In the third condition of exposure, the units were fully ventilated from 1900 hrs. to 0700 hrs. and partially ventilated throughout the day, the ventilators being kept open.

Roorkee Observations

Indoor temperature observations only were taken during April and May 1956. Observations were stopped during the rains, but were resumed again in October. Observations on temperature gradients were also taken from the month of October.

Discussion

The effect of ceiling height on the indoor air temperatures and the vertical temperature gradient have been discussed for the different conditions of exposures in these small units.

Indoor Air Temperature

The thermal damping, depression of maxima, and the time lags have been considered for this study and the data are presented in *Table* XVII. It will be seen from the data that there is little significant difference in the indoor temperatures of these four units either at Roorkee or at Delhi. From the Delhi observations it has been found that the lowest unit is worse than the other three from the thermal point of view. The behaviour of the other units is almost similar.

In Delhi, on introducing night ventilation and partial ventilation during the day, there was an improvement in all units. As regards indoor temperature, there was a decrease of 1·5°F as indicated by the increase of depression. The time-lags were reduced by as much as five hours. The maximum decrease in the lowest unit may be attributed to cross-ventilation due to an additional ventilator. Thermal damping values were also reduced, indicating that the reduction in minima is greater than the reduction in maxima.

In Delhi, on substituting partial ventilation during daytime by fan circulation, there has been an increase in the indoor maxima by nearly 4°F, as indicated by the decrease in the depression. This condition is, therefore, the worst. However, this needs further confirmation, for the climate during this period was the coolest and there were the maximum rains.

Temperature Gradient

Temperature curves and regression lines of the temperature gradients of maxima for the unventilated conditions of exposure are presented both for Roorkee and Delhi units in *Figs.* XII and XIII. Similar curves are also presented for Roorkee units for the values at 4 P.M. in *Fig.* XIV. It will be seen from the *Fig. XII* that up to

3 feet from the ceiling there is a sharp fall in all the units and beyond that they are less steep. This is, however, not marked in the other two figures. The rate of fall is the highest for the lowest unit and for other units it is more or less similar.

In Delhi, the introduction of night ventilation reduced the range of variation by half a degree, the reduction being of the order of 2 to 3°F.

Preliminary study in Occupied Rooms

A short duration experiment was carried out at Roorkee on the rate of rise of indoor temperature and humidity in occupied rooms of different ceiling heights.

The period of observation was one hour at a time. The doors, windows and ventilators were all kept closed. Readings were taken simultaneously, every five minutes, both inside and outside in shade by psychrometers. Wind movements were also observed at 8 ft. level from the ground and 30 ft. away from the rooms.

The results of the observations are presented in *Figs.* XV, XVI and XVII.

It will be seen from the figures that there is no significant rise of temperatures in the rooms when they were occupied by either one person or four persons. The differences between the rates of rise of temperatures in the rooms of different ceiling heights are again not significant with either one or four persons. The same is the case of the rise of humidity. This, however, requires to be confirmed by further detailed experimentation.

Conclusions

The following tentative conclusions can be arrived at from the data.

(i) Little difference was noticed in the indoor temperature of four indentical rooms of 12 ft. by 10 ft. and with ceiling heights varying between 8 ft. to 11 ft. and in four other identical rooms of 11 ft. 6 in. by 9 ft. 6 in. and with ceiling heights varying between 7½ ft. to 12 ft.

(ii) There was little significant difference noticed in the indoor relative humidity of the four occupied identical rooms of different ceiling heights at Roorkee, even when the rooms were kept unventilated.

(iii) There is an improvement in the indoor living conditions in summer by the introduction of night ventilation.

Tentative Recommendations

The recommendations given below are applicable to "hot-dry region". As the experiments were limited in duration, they are tentative and should be accepted as a guide only.

Design features.

(i) In orienting a building two factors are for consideration, insolation and ventilation, and at times these give conflicting indications. For climates as in Delhi the mean wind direction in the afternoon during the monsoon should guide the orientation, a thermally sound roof taking care of the insolation.

(ii) The heating effect of the sun on a building with faulty orientation can be remedied by attention to the roof and by an intelligent use of chajjas and shady trees.

(iii) Closeable ventilators should be provided at ceiling level; permanent ventilators should as far as possible be avoided.

(iv) Heat capacity plays an important role in deciding the thermal performance of a building.

(v) Where no artificial cooling aids are used, thermal diffusivity plays an important part; thermal conductivity alone is not so important.

(vi) As far as thermal comfort is concerned, the roof is the most important component of a building and it should on this account receive special attention.

(vii) The ceiling temperature can be brought down considerably by white washing the exposed surface of the roof.

Materials.

(i) A roof of built up thickness of 6½ in. or more consisting of R.C.C. or reinforced brick work with or without mud-phuska, lime, concrete etc. gave satisfactory results (due to moisture penetration, roofs of reinforced brick work have deteriorated after a time and their use is not generally recommended). R.C.C. roofs upto a thickness of 4½ in. and stone roofs should not be used without some insultation. A.C. sheets, G.I. sheets or Mangalore tile roofing should not be used without a false ceiling.

(ii) 9 in. brick walls in cement, lime or mud mortar with ½ in. plaster on both sides affords adequate thermal protection. 8 in. hollow blocks of concrete or gypsum are not thermally adequate.

Surface Finishes.

(i) White, cream, biscuit and similar light coloured washes are thermally desirable for exterior surfaces.

(ii) Cement wash, red and similar deep colour washes should be avoided.

Dampness penetration.

(i) Where mud is used as an insulating material a waterproof rendering should be used on the roof.

(ii) When using precast roofs, special care is necessary to avoid dampness penetration at the joints.

(iii) Corrugated A.C. and G.I. sheets, if properly laid, may be relied upon as roofing materials.

(iv) Cavity walls and hollow block walls can be safety depended upon.

(v) 4½" thick brick walls, even of first class bricks and with rendering on both sides, have leaked and cannot be trusted.

(vi) 9" brick walls with plaster on both sides have given satisfactory results in the Delhi climate, but may not be adequate in very exposed locations.

Ventilation.

(i) It is not sufficient to prescribe only the window area as a percentage of floor area. The distribution is also important and should be indicated.

(ii) When deciding the location of windows the mean monsoon wind direction during the afternoons should be the guiding factor. The effect of faulty orientation may be remedied to some extent by suitably locating the windows.

(iii) From the point of view of ventilation the width of a window is more important than its height.

Day light illumination

(i) The openings required for adequate ventilation generally produce adequate illumination conditions indoors.

(ii) From the illumination point of view the height of the window is more important than its width.

Ceiling Height

Little difference was noticed in the indoor temperature of four identical rooms of 12 ft. by 10 ft. and with ceiling heights varying between 8 ft. to 11 ft. and in four other identical rooms of 11 ft. 6 in. by 9 ft. 6 in. and with ceiling heights varying between 7½ ft. to 12 ft.

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TABLE I—HOUSE SPECIFICATIONS

House No.	Facing	ROOF Thickness	ROOF Materials used	WALLS Thickness	WALLS Materials used
2	SW	9½"	6" R. C. C. slab with brick flats on top.	10"	Brick in cement mortar with ½" cement plaster on both sides.
3	SW		Corrugated A. C. sheets	8"	Cement concrete hollow blocks.
4	SW	9"	4½" R. C. C. slab with 4½" lime concrete-Bitumen wash on top.	10"	Brick in mud mortar with ½" cement plaster on both sides.
5	SW	6½"	4½" R. B. with 2" lime concrete using brick ballast aggregate. Bitumen wash on top.	10"	Brick in mud mortar with ½" cement plaster on both sides.
6	SW	5"	Two corrugated concrete curved shells each 1½" thick with an air gap of 2".		Same as roof except front and back wall which are 4½" brick in cement mortar.
8	SW	5"	Do.		Do.
9	SW	1½"	Single concrete shell		Do.
10-11	SW		Corrugated A. C. sheets (Gypsum board ceiling from July to Feb. 1956).	14½"	Brick cavity wall with 3" external skin, 2½" hollow partition wall 2½" mud infill and 3½" internal partition.
R-A.	SW	6"	2" brick tiles on wooden rafters with 4" mud phuska on top.	10½"	Do.
51	SW	9"	3" stone slabs with 6" lime concrete using Rubble stone aggregate.	14"	Rubble masonry in lime mortar.
45	NE	2½"	Precast R. C. C. slabs on Strest beams-top bitumen washed with murram sprinkled over it.	9½"	Brick in mud mortar with ½" cement plaster inside.
46	NE	4"	R.C.C. slabs.	10"	Brick in cement mortar with ½" mud plaster inside.
48	NE	5½"	3½" lime concrete using brick ballast aggregate in between two 1" Kotah stone slabs on top and bottom supported on wooden rafters.	10"	Brick in mud mortar with Kotah stone dado upto 3' height.
12	NW	12"	R. C. C. beams with brick filling followed by lime concrete using brick ballast with bitumen wash above it.	14½"	Brick in mud mortar with ½" cement plaster on both sides.
16	NW	6"	2" Precast R. C. C. slabs on R. C. C. Tee beams with 1½" concrete with brick flats on top.	10"	Brick in cement mortar with ½" cement plaster on both sides.
14	NW	11½"	4½" R. C. C. slabs with brick flats in cement mortar on top and mud in between.	10"	Brick in cement mortar with ½" cement plaster on both sides.

TABLE I—*contd.*

House No.	Facing	ROOF		WALLS	
		Thickness	Materials used	Thickness	Materials used.
22	NW	7½"	4½" brick jack arches with lime concrete using brick ballast aggregate in haunches and 3" over the crown and topped with hourrum.	10"	Brick in lime mortar with ½" lime plaster on both sides.
23	NW	6'	2" precast cement concrete tiles over R.C.C. Beams-bitumen wash on top with 4" mud phuska.	9½"	Brick in mud mortar with ½" cement plaster inside.
24	NW	10"	Brick arch.	9½"	Brick in cement mortar with ½" cement plaster inside.
26	SE	6'	Arched and sloping Goona tile roof in lime mortar with lime plaster on both sides.	14½"	Brick in mud mortar with ½" cement plaster on both sides.
27	SE		Corrugated A. C. sheet with gypsum plaster underneath.	8'	Hollow gypsum blocks in gypsum mortar.
29	SE		Do.	13½"	Brick in mud mortar upto 2' 6" above plinth.
30	SE	6½"	3" R. C. C. slabs with mud on top.	10"	Brick in mud mortar above 2' 6" with 2" cement plaster on both sides.
53	S	1½"	Precast vacuum concrete shell.	2½"	Precast vacuum concrete walls.
54	S	6"	4" foamed concrete slabs over prestressed concrete beams with mud phuska on top.	9½"	Brick in mud mortar with ½" cement plaster inside.
41	N	4½"	R.C.C. slab.	9½"	Brick in cement mortar with ½" cement plaster inside.
42	N	7½"	4½" R. C. C. slab with brick flats on top.	10"	Brick in cement mortar with ½" plaster on both sides.
43	N	7"	2" precast R. C. C. tiles on R. C. C. beams with 3" lime concrete using brick ballast aggregate and mud phuska on top.	9½"	Brick in cement mortar with 1½" cement plaster inside.
44	N		Curved A. C. sheets with 2" air gap in between.		Same as roof except 14½" brick wall plastered on both sides upto 3' height on sides and 10" thick brick wall plastered on both sides
65-66	N		Compressed bamboo mat boards and wood chip boards with hardboard ceiling.		Compressed bamboo mat boards fixed on to Chir wood frame work.
33	E	4"	R.C.C. slabs.	8"	Concrete hollow blocks with continuous cavity.

TABLE I—*contd.*

House No.	Facing	ROOF		WALLS	
		Thickness	Materials used	Thickness	Materials used.
36	E	6″	Thatch grass over bamboo trusses and purlins, with timber plank ceiling.		Long walls of reinforced bamboo mud core and front and back walls of timber and bamboos.
37	E	8½″	4½″ R. C. C. slabs with 3½″ lime concrete and cement plaster on top.	9½″	Brick in mud mortar with ½″ cement plaster on inside.
38	E		Mangalore tiles hip and valley roof on wooden rafters.	10″	Brick in mud mortar as panels in R.C.C. frame.
40	E	7½″	4½″ R. C. C. slabs with brick flats on top.	8½″	8″ thick cinder concrete hollow blocks with ½″ cement plaster on inside.
55	E	1½″	Synthetic wood panels	4″	Synthetic wood panels.
57	E	8″	4½″ R. B. with brick flats on top.	10″	Brick in lime mortar with ½″ lime plaster outside and mud plaster inside.
59	E	..	A. C. sheets roof topped over with 1½″ thick mixture of road tar, sand and saw dust in the ratio of 2 : 2 : 1.	75″	1½″ thick R. C. C. panels in grooves at the two ends of R. C. C. pillars with mud filled in the gap.
60	E	..	A. C. sheet over R.C.C. roof trusses and purlins with ceiling of hessian, Rabbit wire mesh sprayed with aerocem mixture.	6″	Aerated cement concrete hollow blocks.
49-50	S	..	A. C. sheet roof with hard board ceiling.	13½″	Double leaf brick cavity wall with 4½″ air gap.
34	E	..	G. I. sheet with chatai sheet.	3″	Brick in cement mortar upto 2′ 9″ above plinth and over this wattle walling plastered on both sides.
35	E	½″	Creosoted shingle proofing on collar trusses.	½″	Vertical wooden board wall.

TABLE II (A)—AREA AND LOCATION OF OPENINGS

(in sq. ft.)

House No.	Facing	Floor Area	North-East			North-West			South-East			South-West			Total Area		
			Window	Ventilator	Glass	Window	Ventilator	Glass	Window	Ventilator	Glass	Window	Ventilator	Glass	Window	Ventilator	Glass
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2 .	SW	100·0	15·0 5·5*	0·25	10·5	..	..	..	..	..	..	10·8 3·2*	0·25	5·6	35· 8·7*	0·5	16·1
3 .	SW	122·7	16·5	0·1	7·4	..	..	..	..	..	..	16·5	2·4	7·4	33·0	2·5	14·8
4 .	SW	100·0	..	0·6	..	..	1·4	4·33	..	..	..	12·8 3·7*	..	6·29	12·8 3·7*	2·0	10·62
5 .	SW	141·3	..	..	0·55	..	..	..	11·5 5·0*	.. 1·5**	.. 7·9	11·4 5·2*	.. 2·0**	7·9	22·9 10·2*	3·5**	16·55
6 .	SW	316·7	..	..	..	11·6	..	10·3	11·6	..	5·5	32·0	3·7	6·0	55·2	3·7	21·8
8 .	SW	254·5	..	..	..	7·8	3·0 in roof	3·2	15·7	..	6·5	..	..	..	23·5	3·0	9·7
9 .	SW	255·1	..	..	..	..	..	..	2·7	..	2·0	24·0	1·1	12·0	26·7	1·1	14·0
10—11 .	SW	135·0	..	..	..	..	..	..	..	..	..	6·3	3·8	1·8	6·3	3·8	1·8

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
R—A	SW	153·0	..	..	..	..	..	..	.. 0·01*	.. 0·31*	..	5·9	..	..	5·91	0·31**	..
51	SW	98·8	..	2·4	..	..	..	..	..	..	..	15·5	2·4	9·0	13·5	4·8	9·0
12	NW	117·9	11·8	0·2	..	11·8	0·2	..	..	0·2	..	..	..	..	23·6	0·6	..
13	NW	118·0	10·5 13·0*	..	6·7	..	..	..	..	..	..	10·5 9·9*	..	5·3	21·0 22·9*	..	12·0
14	NW	92·3	8·1 8·8*	..	6·6	..	..	..	..	..	..	..	..	..	18·1 8·8*	..	6·8
22	NW	104·2	..	..	..	16·5	..	8·0	..	..	..	..	..	..	16·5	..	8·0
23	NW	122·5	..	..	..	17·1	..	8·5	..	3·5	..	..	..	..	17·1	3·3	8·5
24	NW	98·0	..	.. 1·2**	..	..	2.8	2·2	..	..	..	..	..	..	..	2·8 1·2**	2·2
26	SE	114·0	12·0	2·0	5·5	..	..	..	..	4·8	..	4·5	2·0	..	16·5	8·8	5·5
27	SE	142·0	8·8	2·9	..	6·9	1·3	..	..	..	..	..	..	..	15·7	4·2	..
29	SE	120.0	..	..	..	..	..	1.7	12·0	..	7·1	..	..	..	12·0	..	8.8
30	SE	120·0	..	..	..	..	..	2·0	10·5	1·3	6·5	..	..	..	10·5	1·3	8·5
45	NE	103·8	14·0	2·0	6·4	..	..	..	..	..	..	..	1·0	7·0	14·0	3·0	13·4
46	NE	120·0	..	..	..	..	..	..	12·0	..	..	12·0	..	..	24·0	..	..
48	NE	97·3	8·2	0·14	..	..	..	..	8·2	0·14	..	..	..	..	16·4	0·28	..

*Area of Closable ventilator in the window frame.

**Area of closable ventilator.

TABLE II (*b*)—AREA AND LOCATION OF OPENINGS—*contd.*

(in sq. ft.)

House No.	Facing	Floor Area	East			West			North			South			Total Area		
			Window	back Ventilator	Glass	Window	Ventilator	Glass	Window	Ventilator	Glass	Window	Ventilator	Glass	Window	Ventilator	Glass
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
33 .	E	130·4	14·0 1·5*	1·5	2·3	..	..	..	22·8	2·2	4·0	..	..	..	36·8 1·5*	3·7	6·3
34 .	E	121·3	11·5 7·0*	..	..	11·5 7·0*	..	..	11·5 7·0*	..	..	..	..	..	34·5 21·0*	..	..
35 .	E	155·0	18·6	..	17·8	..	..	8·9	18·7	..	8·9	..	..	6·7	37·3	..	42·3
36 .	E	80·5	6·0	.. 5·7**	12·5	..	..	..	..	..	..	16.0	..	8·7	22·0	5·7*	21·2
37 .	E	185·1	19·0 5·0*	..	12·3	..	3·8**	12·3	..	3·8**	12·3	..	.. 1.8**	1·8	19·0 5·0*	9·4**	38·7
38 .	E	119·2	24·0	1·6	12·0	12·6	..	5·5	12·0	1·3	5·5	..	..	..	48·6	2·9	23·0
40 .	E	120·0	6·7	0·6	4·1	..	0·6	1·3	22·0	0·6	8·0	..	..	..	28·7	1·8	13·43
55 .	E	120·2	10·0	..	..	10·0	..	..	..	..	..	..	..	..	20·0	..	..
57 .	E	127·0	12·0	3·3	10·8	..	..	5·8	..	..	5·3	..	..	..	12·0	3·3	21·9
59 .	E	87·3	19·6	1·7	..	9·7	1·7	..	..	..	..	..	..	..	29·3	3·4	..
60 .	E	125·0	6·0	..	..	..	..	..	6·0	..	..	..	..	..	12·0	..	..

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
41 .	N	215·1	..	..	..	11·5	..	..	11·5	7·4	..	..	7·4	..	23·0	14·8	..
42 .	N	108·0	..	1·7	..	..	..	..	19·4	1·7	3·0	19·7	1·7	1·5	39·1	5·1	4·5
43 .	N	206·9	24·0	5·1**	12·3	..	..	..	..	..	24·0	24·0	5·1** 15·1	12·3	48·0	10·2**	28·6
44 .	N	108·2	..	..	..	..	..	..	28·5	13·5	..	..	..	..	28·5	13·5	..
65—66 .	N	141·5	..	..	..	12·0	..	5·9	21·3	..	12·5	..	..	..	33·3	..	18·4
53 .	S	94·9	..	..	..	6·0	..	..	..	..	..	..	..	1·5	6·0	..	1·5
54 .	S	125·5	..	..	..	..	..	..	25·0	..	12·7	25·0	..	12·7	50·0	..	25·4

*Area of closable ventilator in the window frame.

**Area of closable ventilator.

TABLE III-A. AVERAGE (MONTHLY) VALUES OF THERMAL PERFORMANCE OF ROOFS

(Ventilation Nil 24 hours)

House Nos.	Thermal Damping (per cent)						Depression in Maximum (°F)					
	Apr. 55	May 55	Nov. 55	Dec. 55	Jan. 56	Feb. 56	Apr. 55	May 55	Nov. 55	Dec. 55	Jan. 56	Feb. 56
2	79	76	75	75	73	78	23	25	22	17	18	27
3	39	35	27	24	32	32	20	14	13	9	12	15
4	66	55	56	44	64	62	23	26	15	12	15	19
5	52	47*	47	50	50	49	16	21*	12	10	11	15
6	56	51	52	54	51	51	27	121	20	15	14	20
8	50	43	43	49	47	46	22	15	12	10	12	16
9	8	9	3	2	6	8	5	1	2	1	2	2
10-11	9	12	55**	60**	66**	65**	4	13	20**	17**	17**	20**
R-A	44	42	33	40	33	33	20	18	17	7	6	6
51	51	47	40	52	54	53	16	19	12	10	10	16
12	85	80*	85	85	81	81	33*	29	24	21	20	27
13	73	70	65	73	70	72	26	29	20	23	21	25
14	79	79	81	80	77	80	34	21	33	24	26	29
22	71	71*	75	76	71	..	23	25*	19	16	15	..
23	63	65	58	65	57	62	23	22	19	16	12	20
24	82	78	70	72	71	72	37	40	25	19	19	26
26	76	67	71	69	69	65	28	17	25	15	12	16
27	25	20	21	21	22	21	13	10	10	5	8	10
29	9	13	—6	—2	—7	—7	5	7	0	1	2	—1
30	65	72	63	73	62	68	19	16	17	15	13	20
45	35	25	34	34	32	36	5	20	8	8	9	13
46	29	26	22	19	24	20	9	8	5	2	14	4
48	46	40	41	49	52	47	14	14	12	10	14	15
33	25	23*	18	17	17	15	10	8*	16	5	4	5
34	..	..	56	51	56	58	..	..	23	13	19	28
35	37	..	28	..	22	—7	..	..	—11	—8	—7	7
36	..	..	25	40	42	43	..	..	2	5	5	9
37	63	..	60	66	61	61	30	..	22	21	18	25
38	22	..	22	28	25	24	14	..	13	12	10	12
40	68	..	64	73	65	72	29	..	24	24	19	28
55	38	39	36	37	35	36	20	20	15	13	11	16
57	78	78	72	82	72	75	34	34	24	25	20	28
59	37	33	37	38	37	38	21	20	16	12	14	16
60	63	63	..	50	61	65	33	30	17	11	19	27
41	36	38	17	19	20	22	13	12	7	6	9	9
42	69	67	63	70	64	67	28	25	29	18	17	20
43	71	70	69	73	62	71	26	27	22	19	13	21
44	62	62	57	58	56	59	36	38	26	20	21	27
65-66	50	56	..	43	44	44	25	25	8	10	9	13
53	8	12	5	9	2	4	9	4	1	0	—1	0
54	67	67	59	63	63	70	30	23	14	13	15	21

*Indicates opposite kind of ventilation.

**A. C. Sheet roof with Gypsum Board Ceiling.

TABLE. III-B—AVERAGE (MONTHLY) VALUES OF THERMAL PERFORMANCE OF SLABS.

(Ventilation at night only)

House Nos.	Thermal Damping (per cent)					Depression in Maximum (°F)				
	Jun. 55	July 55	Sep. 55	Oct. 55	Mar. 56	Jun. 55	Jul. 55	Sep. 55	Oct. 55	Mar. 56
2	74	68	79	65	79	20	21	25	25	35
3	39	35	35	36	33	15	12	14	13	18
4	68	55	61	57	66	20	17	18	17	22
5	53*	44*	43	42	41	16	14	13	11	16
6	50	48	47	50	53	17	19	17	19	22
8	42	41	47	38	48	12	12	14	11	17
9	9	..	5	4	4	3	3	2	4	0
10-11	..	..	67**	61**	..	..	..	31**	29**	..
R-A	47	30	22	25	36	15	10	5	7	11
51	55	51	43	51	54	14	13	8	15	19
12	83*	79*	81	77	82	27*	23*	22	24	31
13	72	60	60	61	68	28	21	21	20	22
14	73	67..	69	72	74	16	8	14	22	23
22	74*	70*	63	70	..	21*	18*	16	18	..
23	49	..	55	47	60	19	..	8	14	20
24	75	71	73	72	75	32	32	22	28	28
26	56	54	55	63	66	14	15	10	20	15
27	25	23	26	26	23	10	10	10	13	10
29	16	13	..	..	..	4	3	—1	—2	0
30	66	63	46	51	46	19	12	7	10	18
45	35	29	37	28	35	4	6	12	6	11
46	23	22	24	21	24	7	8	5	5	6
48	48	44	35	46	46	16	17	7	17	16
33	23*	17*	14	14	20	7*	5*	5	5	6
34	..	58	69	57	56	..	26	29	34	25
35	..	52	48	..	28	..	19	16	..	7
36	..	61	78	..	59	..	20	44	..	21
37	..	59	46	51	63	..	19	15	14	25
38	..	23	21	22	-22	..	10	12	13	10
40	..	58	41	47	67	..	18	20	17	29
55	38	31	33	33	33	18	13	16	16	15
57	78	66	64	63	77	28	24	20	18	31
59	37	40	44	33	37	20	19	22	17	17
60	65	61	64	56	66	28	26	25	21	24
41	35	31	22	21	26	12	10	6	8	9
42	68	56	50	51	62	20	14	13	17	17
43	74	57	41	54	66	26	18	10	16	19
44	61	54	54	60	57	30	33	30	30	24
66	34	..	..	48	50	11	..	..	16	14
53	11	13	10	11	6	3	5	2	1	1
54	60	47	56	48	66	20	15	9	..	23

*Indicates opposite kind of Ventilation.

**A. C. Sheet roof with Gypsum board ceiling.

TABLE IV.—AVERAGE (MONTHLY) VALUES OF THERMAL PERFORMANCE OF WALLS

(A—Ventilation Nil 24 hours)

Hous No.	Wall Facing	Thermal Damping (per cent) Apr. 55	May 55	Nov. 55	Dec. 55	Jan. 56	Feb. 56	Depression in Maximum (°F) Apr. 55	May. 55	Nov. 55	Dec. 55	Jan. 56	Feb 56
1	2	3	4	5	6	7	8	9	10	11	12	13	14
12	NW	85	82*	72	80	76	..	23	32*	8	11	8	..
10-11	NW	..	..	74	75	82	84	..	..	17	15	15	22
49-50	S	..	..	..	..	85	82	..	..	..	..	45	38
5	SE	..	60*	71	78	76	77	..	25*	25	23	22	27
22	NW	..	70*	75	71	73	..	..	27*	14	12	13	..
48	SE	..	..	66	73	79	77	..	..	29	24	29	34
37	E	..	..	43	61	70	72	..	..	4	5	5	8
40	N	..	..	47	59	60	59	..	..	6	5	5	6
3	SE	..	23	38	42	43	47	..	3	10	7	11	11
27	SE	..	47	64	58	71	65	..	10	22	11	21	24
33	N	43	34*	30	39	36	36	5	6*	1	2	1	2
60	E	..	..	32	32	36	49	..	..	6	6	6	9
59	E	..	..	52	59	55	53	..	..	26	27	27	27
29	SE	..	51	53	57	65	59	..	14	13	15	17	18
53	S	..	..	25	23	26	23	..	..	12	10	14	12

(B—Ventilation at night only)

House Nos.	Wall Facing	Thermal Damping (per cent) June 55	July 55	Sept. 55	Oct. 55	Mar. 56	Depression in Maxima (°F) June 55	July 55	Sept. 55	Oct. 55	Mar. 56
12	NW	81*	80*	64	76	..	18*	16*	16	13	..
10-11	NW	..	..	77	79	..	..	..	27	19	..
49-50	S	..	..	..	..	78	..	..	..	..	30
5	SE	64*	62*	54	66	74	11*	10	15	20	24
22	NW	76*	..	..	..	..	22*	..	..	..	..
48	SE	..	..	..	62	70	..	..	..	27	15
37	E	..	63	60	46	69	..	8	16	7	12
40	N	..	..	..	43	54	..	..	..	2	8
3	SE	27	24	49	41	43	1	2	13	8	8
27	SE	28	54	54	52	57	2	7	6	17	11
33	N	39*	38*	..	21	30	5*	4*	..	1	3
60	E	..	..	..	39	52	..	..	..	6	11
59	E	..	..	..	48	37	..	..	..	20	14
29	SE	36	63	63	53	49	2	2	12	14	10
53	S	..	..	..	28	10	..	..	..	10	4

*Indicates opposite kind of Ventilation.

TABLE V-A 1.—AVERAGE (MONTHLY) VALUES OF THERMAL PERFORMANCE OF HOUSES

(Ventilation Nil 24 hours)

House Nos.	Thermal Damping (Per cent)						Depression in Maxima (°F)					
	Apr. 55	May 55	Nov. 55	Dec. 55	Jan. 56	Feb. 56	Apr. 55	May 55	Nov. 55	Dec. 55	Jan. 56	Feb. 56
2	73	62	61	70	66	79	12	12	12	11	9	15
3	43	37	32	31	28	44	13	10	11	9	8	11
4	56	62	59	71	70	76	14	13	15	12	12	15
5	52	37*	61	64	63	66	9	8*	12	9	8	11
6	41	30	31	40	51	43	8	6	7	6	8	10
8	42	30	29	45	43	46	8	7	9	8	8	10
9	6	..	1	4	11	9	—4	—5	1	−1	0	0
10-11**	45	40	55	60	71	68	6	5	13	9	9	11
R-A	72	56	58	73	70	73	12	10	13	10	10	16
51	66	57	48	68	70	69	14	11	13	11	9	13
12	73	54*	77	82	77	79	16	16*	18	14	13	19
13	73	63	73	78	79	74	11	10	17	14	15	16
14	77	68	80	80	76	82	12	12	15	12	12	17
22	67	54*	79	81	76	..	12	14*	18	14	11	..
23	65	56	69	83	77	74	10	9	16	13	12	16
24	52	54	72	73	60	78	11	13	20	17	15	19
26	62	60	71	79	81	80	10	10	15	11	12	15
27	43	33	50	47	47	51	9	10	16	12	11	14
29	44	43	48	47	52	58	8	10	14	10	11	15
30	66	76	67	82	74	76	14	14	17	15	14	17
45	42	..	53	67	63	69	10	8	13	12	11	14
46	43	44	51	48	54	54	10	8	11	7	6	9
48	61	64	60	71	72	71	9	10	14	12	11	14
33	47	31*	46	53	47	50	10	11*	11	8	6	7
34	..	..	32	48	31	32	..	..	9	6	6	7
35	..	..	7	14	10	12	..	..	5	2	4	6
36	..	..	29	32	34	20	..	..	9	6	6	9
37	68	..	64	77	71	72	12	..	17	13	11	16
38	45	..	37	54	47	47	13	..	14	12	13	15
40	58	..	58	69	66	71	10	..	17	13	12	18
55	43	31	45	51	47	47	7	7	14	10	9	13
57	68	64	72	78	78	77	13	12	16	14	13	18
59	34	30	35	45	33	40	8	9	12	10	9	13
60	53	46	54	68	53	62	10	11	19	16	12	17
41	38	44	..	..	..	..	11	8	..	..	..	..
42	64	64	67	68	59	75	11	11	16	13	11	14
43	63	70	71	83	75	79	10	11	16	11	11	14
44	38	37	51	52	56	49	9	9	13	11	11	12
65-66	9	26	6	21	8	18	2	4	4	3	1	5
53	23	..	27	40	36	26	6	4	11	8	9	9
54	59	61	58	63	58	64	9	11	13	10	4	11
49-50	..	..	..	..	63	60	..	..	..	..	8	10

*Indicates opposite kind of Ventilation.

**Gypsum board ceiling after June.

TABLE V-B 1.—AVERAGE (MONTHLY) VALUES OF THERMAL PERFORMANCE OF HOUSES

(Ventilation at night only)

House Nos.	Thermal Damping (per cent)					Depression in Maxima (°F)				
	June 55	Jul. 55	Sep. 55	Oct. 55	Mar. 56	June 55	Jul. 55	Sep. 55	Oct. 55	Mar. 56
1	2	3	4	5	6	7	8	9	10	11
2	33	39	46	39	58	9	11	4	14	10
3	16	16	13	26	27	7	8	2	6	9
4	46	41	31	55	68	11	13	4	13	9
5	42*	37*	29	41	61	7*	8*	3	9	9
6	27	..	..	15	24	5	4	..	5	4
8	14	..	19	10	32	2	5	—2	8	4
9	..	..	23	—21	—6	—5	—5	—11	—1	—8
10-11**	..	..	29	40	..	..	..	10	11	..
R-A	63	52	..	54	63	6	69	..	9	8
51	44	..	58	57	63	7	10	8	12	10
12	74*	72*	58	71	77	10*	12*	12	16	14
13	50	49	57	54	67	5	9	8	11	15
14	43	61	61	58	71	8	10	7	12	14
22	60*	66*	55	60	..	9*	12*	6	12	..
23	47	43	58	64	68	4	..	10	14	8
24	..	47	77	77	65	8	13	9	18	9
26	45	43	40	67	75	6	9	5	14	10
27	18	28	34	35	37	8	9	8	14	5
29	22	30	35	33	35	7	11	8	14	6
30	58	54	75	60	75	10	14	8	16	9
45	36	30	34	44	62	6	9	3	10	11
46	17	25	14	21	43	3	5	3	10	3
48	50	38	..	53	63	5	8	..	14	6
33	29*	32*	37	38	39	5*	7*	2	6	4
34	..	22	..	12	23	..	6	..	7	—1
35	..	..	..	16	4	..	1	3	4	—1
36	..	28	..	18	29	..	10	..	8	4
37	..	..	..	51	65	..	14	6	14	10
38	..	33	35	35	37	..	16	1	12	10
40	..	47	..	45	62	..	15	..	13	10
55	16	22	..	28	33	5	6	1	10	5
57	43	49	60	48	79	5	11	7	13	11
59	..	16	14	25	37	3	8	..	10	6
60	36	19	32	43	60	6	10	7	17	13
41	18	24	30	..	41	2	4	..	..	10
42	44	51	53	46	71	7	10	7	11	..
43	39	42	46	49	70	7	9	7	12	13
44	..	33	48	42	36	5	9	7	9	10
65-66	..	13	20	3	12	0	3	2	3	6
53	5	8	15	26	5	1	2	6	7	6
54	33	33	33	46	60	5	10	7	12	11
49-50	..	..	..	..	56	..	..	..	..	6

*Indicates opposite kind of Ventilation.

**Gypsum board ceiling after June.

TABLE VI-A.—AVERAGE VALUE OF TEMPERATURE MAXIMA (°F)

(Ventilation Nil 24 hours.)

Note :—

A.T. = Air Temperature. C.T. = Ceiling Temperature. I.W.T. = Internal Wall Temperature

House Nos.	April 1955 Shade Temp. = 93 ,, Range = 26			May 1955 Shade Temp. = 101 ,, Range = 28			November 1955 Shade Temp. = 85 ,, Range = 30			December 1955 Shade Temp. = 74 ,, Range = 25			January 1956 Shade Temp. = 72 ,, 1st Range = 23			February 1956 Shade Temp. = 81 ,, 1st Range = 32		
..	A.T.	C.T.	I.W.T.	A.T.	C.T.	I.W.T.	A.T.	C.T.	I.W.T	A.T.	C.T.	I.W.T.	A.T.	C.T.	I.W.T.	A.T.	C.T.	I.W.T.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
2	81	85 107£	..	89	94 119£	..	73	74 95£	..	63	64 81£	..	63	64 82£	..	66	69 96£	..
3	80	91 111£	..	91	103 117£	94 97£	74	96 109	77 86£	65	84 93£	67 74£	64 61£	81 93£	65 75£	70 ..	93 108£	72 83£
4	79	88 111£	..	88	97 123£	..	70	74 89£	..	62	65 77	..	60	64 78£	..	62	72 91£	..
5	84	95 111£	..	93£	105 126£	87 112£	73	80 92£	72 97£	65	71 81£	63 86£	64	71 82£	65 86£	70	80 95£	71 98£
6	85	95 112	..	95	105 125£	..	78	82 109£	..	68	71 86£	..	64	70 84£	..	71	79 99£	..
8	85	93 114£	..	94 106	104 119£	..	76	82 94£	..	66	71 81£	..	64	70 82£	..	71	79 95£	..

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
9	97	113 118£	..	..	124 125£	..	84	93 95£	..	75	80 81£	..	72	79 81£	..	81	94 96£	..
10-11**	87	122 126£	..	96	126 140£	..	72	84 104£	69 86£	65	75 92£	62 77£	63	71 88£	62 77£	70	79 99£	67 88£
R-A	81	93 113£	..	91	106 124£	..	72	82 89£	..	64	72 79£	..	62	71 77£	..	65	78 85£	..
49-50	..	..	..	..	..	..	..	..	..	..	..	..	64	..	64 104£	71	..	71 108£
51	79	92 108£	..	90	102 121£	..	72	78 91£	..	63	66 76£	..	63	66 76£	..	68	74 90£	.. ..
65-66	91	88 113£	..	97	94 119£	..	81	80 88 £	..	71	71 81£	..	71	72 80£	..	76	76 89£	..
12	77	79 112£	..	85*	87 116£	73 104£	67	70 94£	64 73£	60	61 82£	57 68£	59 ..	61 81£	57 65£	62	65 92£	..
13	82	86 112£	..	91	93 122£	..	68	71 91£	..	60	61 83£	..	57	59 80£	..	65	68 93£	..
14	81	84 118£	..	89	88 109£	..	70	74 107	..	62	65 89£	..	60	64 90£	..	54	71 100£	..
22	81	83 106£	..	87*	91 116£	84 111£	67	69 88£	61 76£	60	60 76£	57 69£	61	62 77£	59 71£	..	..	..
23	83	91 114£	..	92	98 119£	..	69	75 94£	..	61	64 80£	..	60	66 78£	..	65	71 91£	..
24	82	84 121£	..	88	92 132	.. ..	65	70 95	..	57	61 79£	.. ..	57	60 80£	..	62	68 94£	..

†=£

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
26	83	86 115£	..	91	95 112£	..	70	75 99£	..	63	64 79£	..	60	64 76£	..	66	72 87£	..
27	84	104 117£	..	91	114 124£	91 101£	69	91 101£	69 91£	62	78 83£	60 71£	61	78 86£	62 84£	67	90 100£	70 94£
29	85	111 116£	..	91	116 123£	85 98£	71	99 99£	72 85£	64	87 88£	63 78£	61	87 88£	61 77£	66	98 98£	6 83£
30	79	86 105 £	..	87	95 111£	..	68	72 89£	..	59	61 76£	..	58	59 71£	..	64	67 87£	..
45	83	95 100£	..	93	107 127£	..	72	85 93£	..	62	73 81£	..	61	71 81£	..	67	82 95£	..
46	83	100 109 £	..	93	111 119£	..	74	85 90£	..	67	77 79£	..	66	74 88£	..	72	86 90£	..
48	84	95 109£	..	91	105 119£	..	71	79 91£	73 102£	62	67 78£	64 97£	61	66 79£	64 92£	67	75 93£	70 103£
33	83	99 108£	..	90*	108 116£	89 96£	74	90 106£	71 72£	66	79 84£	63 73£	66	80 83£	66 66£	74	92 97£	72 74£
34	..	..	..	..	..	..	76	79 102£	..	68	71 84£	..	66	68 87£	..	74	77 105£	..
35	..	..	..	..	..	..	80	89 78£	..	72	78 70£	..	68	77 70£	..	75	83 90£	..
36	..	..	..	..	..	..	76	77 79£	..	68	69 74£	..	66	67 72£	..	72	73 82£	..
37	81	91 121£	..	..	..	..	68	75 97£	67 71£	61	65 86£	60 72£	61	66 84£	61 66£	65	72 87£	64 72£

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	1
38	80	117 131£	..	..	..	..	71	93 106£	..	62	82 94£	..	59	79 89£	..	66	93 105£	..
40	83	88 116£	..	..	..	..	68	73 97£	63 70£	61	62 87£	56 69£	60	63 81£	55 60£	63	66 95£	58 64£
55	86	104 124£	..	94	111 130£	..	71	86 101£	..	64	78 91£	..	63	76 87£	..	68	84 100£	..
57	80	83 117£	..	89	94 128£	..	69	72 95£	..	60	63 88£	..	59	64 84£	..	63	68 96£	..
59	85	110 131£	..	92	114 134£	..	73	88 103£	71 97£	64	80 92£	61 97£	63	79 92£	62 88£	68	86 102£	67 94£
60	83	89 122£	..	90	98 128£	..	66	73 90£	62 68£	58	66 76£	55 68£	60	65 83£	54 61£	64	71 97£	58 67£
41	82	93 106£	..	93	104 116£	..	92	102 108£	..	79	88 93£	..	79	85 93£	..	87	96 106£	..
42	82	85 113£	..	90	94 118£	..	69	75 103£	..	61	63 81£	..	61	65 82*	..	67	73 93£	..
43	83	82 108£	..	90	94 120£	..	69	70 92£	..	63	62 81£	..	61	64 77£	..	67	71 92£	..
44	84	86 123£	..	92	95 133£	..	72	79 105£	..	63	70 90£	..	61	68 90£	..	69	76 102£	..
53	87	116 125£	..	97	118 122£	..	74	78 78£	82 94†	66	67 68£	73 92£	63	66 65£	72 86£	72	81 81£	75 88£
54	84	93 123£	..	90	93 116£	..	72	73 87£	..	64	63 77£	..	63	63 78£	..	70	70 92£	..

N.B. *Indicates opposite condition of exposure for all the temperatures of the house.
**Gypsum board ceiling was provided in No. 10-11 after June.
†Figures indicate temperatures of corresponding external surfaces.

TABLE VI-B.—AVERAGE VALUE OF TEMPERATURE MAXIMA (°F)

Ventilation at night

House No.	June 1955 Shade Temp=102 Shade Range=27			July 1955 Shade Temp= 99 Shade Range=17			September 1955 Shade Temp= 90 Shade Range=15			October 1955 Shade Temp= 88 Shade Range=21			March 1956 Shade Temp= 85 Shade Range=24		
	Air Temp.	Ceil-ing Temp.	Inter-nal Wall Temp.	Air Temp.	Ceil-ing Temp.	Inter-nal wall Temp.	Air Temp.	Ceil ing Temp.	Inter-nal wall Temp.	Air Temp.	Ceil-ing Temp.	Inter-nal wall Temp.	Air Temp.	Ceil-ing Temp.	Inter-nal wall Temp.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	93	96 115†	..	88	91 112†	..	86	87 112£	..	74	88 103£	..	75	79 115£	..
3	95	102 116£	97 98†	91	101 113†	91 93†	88	104 108†	87 100£	82	93 106†	79 87†	76	95 113†	78 86£
4	91	98 118†	..	86	95 113£	..	86	94 112†	..	75	82 99†	..	76	85 107†	..
5	95*	105 121†	95 106†	91*	102 116£	91 101†	87	98 111†	86 100£	79	88 100†	78 98†	76	88 105†	76 100†
6	97	106 123†	..	95	101 120£	..	..	104 121†	..	83	89 108†	..	81	92 115†	..
8	100	106 118†	..	94	101 113£	..	92	103 116†	..	80	91 102†	..	81	91 108†	..
9	107	120 122†	..	104	116 119£	..	101	114 116†	..	89	99 103†	..	93	109 109†	..

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10—11**	..	..	..	..	..	..	80	91 122†	81 108†	77	88 117†	76 94†	.. ..	.. ..	.. ..
R-A	96	108 123†	..	90	104 114†	..	91	110 115†	..	79	88 86†	..	77	94 105†	..
49—50	..	..	..	..	..	..	..	..	..	..	..	..	79	..	79 109†
51	95	103 116†	..	89	99 112†	..	82	97 105†	..	76	83 97†	..	75	83 102†	..
65—66	102	101 112†	..	96	77 100†	..	88	.. ..	..	85	.. ..	..	79	81 94£	..
12	92*	93 120†	88 106†	87*	91 113£	84 100£	78	86 108†	78 94†	72	76 100†	69 81£	71	74 105†	..
13	97	101 129†	..	90	191£	..	82	85 107†	..	77	85 105†	..	70	75 98†	..
14	94	95 110†	..	89	80 88†	..	83	85 99†	..	76	80 102†	..	71	75 98†	..
22	93*	97 117†	90 112†	87†	90 108†	..	84	88 103†	..	75	77 95†	..	..	..	..
23	98	105 124†	..	..	..	..	80	89 97†	..	74	80 94£	..	77	82 102†	..
24	94	97 129†	..	86	88 120†	..	81	90 112†	..	70	76 104†	..	76	81 109†	..
26	96	101 114†	..	90	97 115†	..	85	94 102†	..	74	82 101†	..	75	82 97†	..

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
27 . .	94	115 126†	94 95†	90	113 124†	89 96†	82	98 108†	81 87†	74	94 107†	76 93†	80	101 112†	81 92†
29 . .	95	117 121†	92 94†	88	119 122†	89 91†	82	106 105†	83 94†	74	103 101†	75 89†	79	112 113†	78 88†
30 .	92	98 117†	..	85	91 103†	..	82	86 93†	..	72	77 87†	..	76	80 98†	..
45 . .	96	107 111†	..	90	104 110†	..	87	106 117†	..	78	92 98†	..	74	88 100†	..
46 . .	99	116 123†	..	94	111 119†	..	87	98 103†	..	78	89 95†	..	82	99 105†	..
48 . .	97	107 124†	..	91	105 122†	..	..	98 105†	..	74	82 99†	74 101†	79	90 106†	84 99†
33 . .	97*	111 119†	94 99£	92*	109 117†	92 96†	88	107 113†	86 87£	82	99 104†	79 80†	81	101 107†	79 82†
34 . .	..	..	..	93	94 120†	..	90	90 119†	..	81	82 116†	..	86	90 115†	..
35 . .	..	..	..	98	90 108†	..	87	89 105†	..	84	..	..	86	92 99†	..
36 . .	..	..	..	89	88 108†	..	88	88 133†	..	80	.. ..	..	81	83 103†	..
37 .	..	..	..	85	91 110†	..	84	95 111†	..	74	84 98†	73 80†	75	83 108†	77 89†
38 . .	..	..	..	83	110 120†	..	89	108 120†	..	76	110 113†	..	75	104 114†	..

40	..	..	..	84	91 109†	..	88	95 114†	..	75	80 97†	71 73†	75	79 108†	71 79†
55	97	111 129†	..	93	108 121†	..	89	104 120†	..	78	92 108†	..	80	97 112†	..
57	97	100 128†	..	88	93 117†	..	83	90 110†	..	75	79 97†	..	74	80 111†	..
59	99	115 135†	..	91	107 125†	..	..	105 126†	..	78	96 112†	75 96*	79	101 118†	75 89†
60	96	99 127†	..	89	94 120†	..	83	91 116†	..	71	78 99†	68 75†	72	80 104†	66 77†
41	100	111 122†	..	95	79 89†	..	..	111 117†	..	..	117 125†	..	75	84 93†	..
42	95	99 119†	..	89	81 96†	..	83	85 98†	..	77	85 102†	..	..	.. 97†	..
43	95	100 126†	..	90	79 97†	..	83	86 92†	..	76	79 93†	..	72	77 96†	..
44	97	101 132†	..	90	75 108†	..	83	90 120†	..	79	85 105†	..	75	82 106†	..
53	101	121 123†	..	97	77 82†	..	84	95 97†	..	81	92 93†	83 93£	79	91 92†	77 81†
54	97	101 121†	..	89	78 93†	..	83	85 92†	..	76	..	..	74	74 97†	..

N. B. *Indicates opposite condition of exposure for all the temperatures of the house.

**Gypsum board ceiling was provided in No. 10—11 after June.

£Figures indicate temperature of corresponding external surfaces.

TABLE VII—AVERAGE (SEASONAL) VALUES OF THERMAL PERFORMANCE OF ROOFS

House No.	Thermal Damping (per cent)						Depression in Maxima (°F)					
	Dry Summer		Wet Summer		Winter		Dry Summer		Wet Summer		Winter	
	Ventilation		Ventilation		Ventilation		Ventilation		Ventilation		Ventilation	
	Nil.	Night	Nil.	Night	Nil.	Night	Nil.	Night	Nil.	Night	Nil.	Night
1	2	3	4	5	6	7	8	9	10	11	12	13
(A) *Cement Concrete Roof.*												
14	79	73	..	69	80	74	28	16	..	15	28	23
2	78	74	..	70	75	79	24	20	..	24	21	35
4	61	68	..	57	57	66	24	20	..	18	15	22
37	63	..	..	52	62	63	30	..	..	16	21	25
40	68	..	..	49	68	67	29	..	..	18	24	29
42	68	68	..	52	66	62	26	20	..	15	21	7
43	71	74	..	51	69	66	26	26	..	16	19	19
30	68	66	..	53	66	46	18	19	..	10	16	18
13	71	72	..	60	70	68	27	28	..	21	22	22
23	64	49	..	45	60	60	22	19	..	9	17	20
54	67	60	..	50	63	66	27	20	..	9	16	23
6	54	50	..	48	52	53	24	17	..	18	17	22
8	46	42	..	42	46	48	19	11	..	12	13	17
41	37	35	..	25	..	26	13	11	..	8	7	9
33	24	23	17	14	17	20	9	8	5	5	7	6
46	28	23	..	23	21	24	8	7	..	6	6	6
45	30	35	..	31	34	35	13	4	..	8	9	11
9	8	9	..	5	5	4	3	3	..	3	2	1
3	10	11	..	11	5	6	6	3	..	3	0	11
(B) *Brick Roof.*												
12	84	80	79	79	83	82	30	29	23	23	23	31
24	79	75	..	72	71	75	39	32	..	27	22	28
57	78	78	..	64	75	77	34	28	..	21	24	31
22	72	71	70	67	74	..	22	25	18	17	17	..
5	53	47	44	42	49	41	16	21	14	12	12	16
26	71	56	..	57	68	66	23	14	..	15	17	15
R-A	43	47	..	25	35	36	19	15	..	7	7	11
38	22	..	..	22	25	22	14	..	..	12	12	10
(C) *Stone Roof.*												
51	49	55	..	48	49	54	17	14	..	12	12	19
8	43	48	..	41	47	46	14	16	..	17	13	16
(D) *A.C. Sheet Roof.*												
59	35	37	..	39	37	37	20	20	..	19	15	17
60	63	65	..	61	54	66	32	28	..	24	18	24
44	62	61	..	56	57	57	37	30	..	31	23	24
10-11	11	12	..	64*	61*	..	4	3	..	30*	19*	..
27	22	25	..	25	21	23	11	10	..	11	8	10
3	37	39	..	35	29	33	17	15	..	13	12	18
29	11	16	..	..	..	..	6	4	..	..	..	..

*Gypsum board ceiling.

1	2	3	4	5	6	7	8	9	10	11	12	13
				(E) *G.I. Sheet Roof.*								
34**	..	..	..	61	55	56	..	..	..	29	21	25
				(F) *Grass and Wooden Roof.*								
36	..	..	..	57	..	59	..	..	..	23	5	21
35	..	..	..	30	..	28	..	..	..	10	..	7
65-66	53	34	..	38	42	50	25	11	..	11	10	14
55	38	38	..	32	36	33	20	17	..	15	14	15

**G.I. Sheet roof with Chatai ceiling.

TABLE VIII—AVERAGE (SEASONAL) VALUES OF THERMAL PERFORMANCE OF WALLS

House No.	Wall Facing	Wall Thickness (inch)	Thermal Damping (per cent)						Depression in Maxima (°F)					
			Dry Summer		Wet Summer		Winter		Dry Summer		Wet Summer		Winter	
			Ventilation		Ventilation		Ventilation		Ventilation		Ventilation		Ventilation	
			Nil	Night	Nil	Night	Nil	Night	Nil	Night	Nil	Night	Nil	Night
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
12	NW	14½	83	82	80	70	..	..	21	32	16	14	..	..
10—11	NW	14½	83	..	..	78	79	..	21	..	..	23	17	..
49—50	S	13½	..	..	..	..	84	78	..	..	..	..	41	31
5	SE	10	64	60	62	60	76	74	11	17	10	17	24	24
22	NW	10	76	70	...	..	73	..	22	27	..	..	13	..
48	SE	10	..	..	..	62	74	70	..	..	..	27	29	15
37	E	9½	..	..	..	56	62	69	..	..	..	10	6	12
40	N	8	..	..	..	43	56	54	..	..	..	2	6	8
3	SE	8	..	..	..	38	43	43	..	..	..	8	10	8
27	SE	8	47	28	..	53	65	57	10	2	..	10	20	11
33	N	88	39 39*	34	38	21	35	30	5 10*	6	4	1	2	3
60	E	6	..	..	..	39	37	52	..	..	..	6	7	11
59	E	5	..	..	..	47	55	37	..	..	..	20	27	14
29	SE	4½	52	36	..	60	59	49	14	2	..	9	16	10
53	S	2½	..	..	..	28	24	10	..	..	..	9	12	4

Cavity ventilated during Night only.

TABLE IX—AVERAGE (SEASONAL) VALUES OF THERMAL PERFORMANCE OF HOUSES

House No.	Thermal Damping (per cent)						Depression in Maxima (°F)					
	Dry Summer Apr.-June		Wet Summer July-Oct.		Winter Nov-Mar.		Dry Summer Apr.-June		Wet Summer July-Oct.		Winter Nov-Mar.	
	Ventilation		Ventilation		Ventilation		Ventilation		Ventilation		Ventilation	
	Nil.	Night	Nil.	Night	Nil.	Night	Nil.	Night	Nil.	Night	Nil.	Night
2	68	33	..	31	69	58	12	9	..	10	12	10
3	33	16	..	18	34	27	11	7	..	5	10	9
4	59	46	..	42	69	68	13	11	..	10	13	9
5	47	37	37	35	63	61	8	8	8	6	10	9
6	35	27	..	15	41	24	7	5	..	5	8	4
8	36	14	..	19	41	32	7	2	..	4	9	4
9	—5	—25	..	2	6	—6	—5	—5	..	—6	0	—8
10-11	43	46	..	34*	63*	..	5	..	..	11*	11*	..
R-A	64	63	..	53	68	63	11	6	..	9	12	8
49-50	..	..	..	..	62	56	..	..	..	..	9	6
51	62	44	..	58	64	63	13	7	..	10	11	10
45	42	36	..	36	63	62	9	6	..	7	13	11
46	44	17	..	20	52	43	9	3	..	6	8	3
48	62	50	..	45	69	63	9	5	..	11	13	6
12	73	54	72	64	79	70	13	16	12	14	16	14
13	68	49	..	53	76	67	11	5	..	9	15	15
14	72	43	..	60	79	71	12	8	..	10	14	14
22	64	54	66	57	78	..	11	14	12	9	14	..
23	61	47	..	55	76	68	9	4	..	12	14	8
24	53	..	..	67	71	65	12	8	..	13	18	9
26	61	45	..	50	78	75	10	6	..	9	13	10
27	38	18	..	32	49	37	9	8	..	10	13	5
29	43	22	..	33	57	45	9	7	..	11	13	6
30	71	58		63	75	75	14	10	..	13	16	9
53	23	5	..	26	32	5	5	1	..	5	9	6
54	60	33	..	37	61	60	10	5	..	10	9	11
41	41	17	..	27	..	41	9	2	..	4	..	10
42	64	43	..	50	67	71	11	7	..	9	13	..
43	67	39	..	46	77	70	11	7	..	9	13	13
44	37	..	..	41	52	36	9	5	..	8	12	10
65-66	17	..	..	17	13	11	3	0	..	3	4	6
33	38	32	32	38	49	39	7	11	7	4	8	4
36	..	..	..	23	29	29	..	..	..	9	8	4
37	68	..	..	51	71	65	12	..	..	11	14	10
38	45	..	..	34	46	37	13	..	..	10	13	10
40	58	..	..	46	66	62	10	..	..	14	15	10
55	37	16	..	25	47	33	7	5	..	6	11	5
57	66	43	..	52	76	79	13	5	..	10	15	11
59	32	..	..	18	38	37	9	3	..	9	11	6
60	49	36	..	32	59	59	11	6	..	11	16	13
34	..	..	..	17	35	23	..	..	..	4	7	—1
05	..	..	..	16	11	4	..	..	..	3	4	—1

*Gypsum ceiling below roof.

TABLE X

Kindly see the text. (Page No. 11).

TABLE X—EFFECT OF WHITE WASHING THE ROOFS

House No.	Conditions of exposure	Before white wash		After white wash	
		Thermal damping (percent)	Depression in ceiling Max. w.r.t. shade Max. (°F)	Thermal damping (percent)	Depression in ceiling Max w.r.t. shade Max. (°F)
33	Unventilated (24 hours)	15	—11	18	—3
41	Ventilated (at night)	26	—4	29	0

TABLE XI—THERMAL BEHAVIOUR OF HOUSE NO. 10-11 UNDER DIFFERENT TREATMENTS.

Sl. No.	Treatment	Conditions of Exposure	House		Roof		Wall	
			Ther. Damp (per cent)	Dep. in Max. (°F)	Ther. Damp (per cent)	Dep. in Max. (°F)	Ther. Damp (per cent)	Dep. in Max. (°F)
1	2	3	4	5	6	7	8	9
1	Untreated 24 hours Wall cavity Unventilated Roof Gap. do.	Unventilated (doors and windows shielded)	39	4	11	4	..	..
2	Celotax ceiling 24 hours. Wall cavity: Unventilated. Roof Gap. do.	Unventilated (doors and windows shielded)	56	9	72	26	84	21
3	Celotax ceiling 24 hours. Wall cavity.—Ventilated. Roof Gap—Unventilated.	Unventilated (door and windows shielded)	59	10	74	30	87	28

1	2	3	4	5	6	7	8	9
4	Celotax ceiling 24 hours. Wall cavity—Ventilated. Roof Gap. do.	Unventilated (door and windows shielded)		8	73	26	86	26
5	Celotax ceiling 24 hours. Wall cavity—Ventilated. Roof Gap. do.	Night ventilation (doors & windows shielded)	37	12	68	26	83	25
6	Celotax off at night and up in day. Wall cavity—Ventilated. Roof Gap. do.	Night ventilation (doors and windows shielded)	31	8	..	34	79	31
7	Gypsum Board—24 hours. Wall cavity—Ventilated. Roof Gap. do.	Night ventilation (doors and windows shielded)	36	13	64	28	79	27
8	Gypsum Board—24 hours. Wall cavity—Ventilated. Roof Gap. do.	Unventilated (doors and windows shielded)	63	7	68	22	80	19
9	Untreated— Wall cavity—Unventilated. Roof Gap. Partly Ventilated.	Unventilated (doors and windows shielded).	40	1	17	5	77	20
10	Celotax ceiling. 24 hours. Wall cavity—Unventilated. Roof Gap.—Partly Ventilated.	Unventilated (doors and windows shielded).	57	5	68	23	90	27
11	Gypsum Board—off at night and up during day. Wall cavity. Ventilated. Roof gap-fully Ventilated at night and partly during day.	Night ventilated (even doors opened at night).	43	11	..	30	76	25

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TABLE XII

(A) RATE OF COOLING A . HOUSE UNVENTILATED

House No.	June			November			February		
	Out door rate 1·25			Out door rate 1·90			Out door rate 2·04.		
	Air	Ceiling	Wall	Air	Ceiling	Wall	Air	Ceiling	Wall
5	0·71	1·48	0·70	0·84	1·63	0·94	0·72	1·59	0·78
22	0·45	0·57	0·50	0·42	0·67	0·47	..	..	..
33	1·01	2·00	1·00	1·15	2·22	1·08	1·06	2·51	1.09
12	0·34	0·40	0·30	0·52	0·47	0·42	0·44	0·56	..

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(*B*) *Houses Ventilated*

House No.	May			October			March		
	Out door rate 1·95			Out door rate 1·43			Out door rate 1·75		
	Air	Ceiling	Wall	Air	Ceiling	Wall	Air	Ceiling	Wall
5	1·25	2·1	0·72	0·93	1·72	0·86	0·82	1·56	0·78
22	0·97	0·89	1·14	0·44	0·61	..	..	..	..
33	1·43	2·4	1·47	1·06	2·22	0·88	1·19	2·40	1·12
12	0·92	0·70	0·12	0·27	0·57	0·33	0·39	0·58	..

TABLE XIII—REFLECTION COEFFICIENT OF WALL SURFACE (FOR VISIBLE LIGHT)

House No.	Texture of Wall Surfaces	Colour Wash	Reflection Co efficient (percent)	
			Clear day	Cloudy day
2	Plastered	Light yellow	59·7	55·7
3	Concrete blocks smooth	Cement	34·4	29·9
4	Plastered	Light yellow	55·7	46·3
5	,,	Grey	47·4	50.8
6	Brickwork	Light yellow	52·0	55·7
9	,,	White	64·0	61.1
10—11	,,	,,	26·7	26·1
R—A.	Mud Plaster	Reddish (no wash)	22·7	30·0
12	Plastered	Greyish	64·0	67.0
13	,,	Light yellow	61·1	52·0
14	Brickwork	Yellow	57·0	58·3
22	,,	Red	59·7	70·2
23	,,	Reddish(no wash)	59·7	..
24	Plastered	White	64·0	61·1
26	,,	,,	54·5	61·1
27	Gypsum block (smooth)	Yellow	53·2	57·0
29	Plastered	Light yellow	57·0	61·1
33	Cement concrete block (smooth)	Greyish (no wash)	36·0	35·2
34	Cement plastered	Light yellow	53·2	38·5
35	Wood	Chocholate	23·8	21·9
36	Bamboo top surface plaster	Greenish	48·5	43·2
37	Brickwork	Red	18·9	14·7
38	Plastered	Light yellow	64·0	44·3
40	Cinder blocks	Deep grey (no wash)	36·8	..
41	Brick work	Red	21.7	24·3
42	Plastered	Light yellow	57·0	52·0
43	,,	Yellow	48·5	53·2
44	,,	White	..	67·0
45	Brick Work	Yellow	53·2	46·3
46	,,	,,	52·0	53·2
48	,,	,,	48·5	53·2
51.A	Stone Rendom rubble Masonry	White	61·1	54·4
53	Vacuum concrete	Deep grey glossy	53·2	49·7
54	Brick Work	Light Yellow(Finish)	49·7	48·5
55	Wooden panel	Smooth yellow	34·4	37·7
59	R.C.C. Panels Smoothly plastered	Building grey	61·1	57·1
60	Aerated Concrete	White	65.5	54.5
8	Brick work	,,	65.5	54·5
30	Plastered	Light Yellow	57·0	59·7
57	,,	,,	58·3	47·4

TABLE XIV—VENTILATION OBSERVATIONS

House No.	Facing	EFFECTIVE VENTILATION (per cent)	
		Outside wind Direction—E.	Outside wind Direction —S.E.
2	SW	37·1	18·8
3	SW	54·7	55·7
4	SW	25·0	36·6
5	SW	51·2	22·1
6	SW	100·0	21·4
8	SW	87·3	62·0
10—11	SW	46·0	..
R—A	SW	70·8	32·9
51	SW	31·4	..
45	NE	27·2	100·0
46	NE	36·8	31·8
48	NE	45·0	18·2
12	NW	37·1	19.2
13	NW	..	25·9
14	NW	..	10·0
22	NW	24·8	19·1
23	NW	23·4	22·8
24*	NW	55·0	17·9
26	SE	53·3	12·9
27	SE	57·7	21·6
29	SE	25·9	11·4
30	SE	21·4	10·7
53	S	32·0	..
54	S	..	..
41	N	33·2	21·2
42	N	74·0	19·9
43	N	51·3	30·9
44	N	34·6	37·8
65—66	N	40·0	..
33	E	50·0	45·7
34	E	29·4	29·8
35	E	32·8	24·4
36	E	27·1	15·8
37	E	31·9	21·5
38	E	28·2	28·8
40	E	28·7	37·5
55	E	55·5	17·4
57	E	22·4	41·8
59	E	26·4	..
60	E	45·5	..

* Door was kept open during observations.

TABLE XV.—ILLUMINATION OBSERVATIONS

House No.	Facing	Effective Illumination (Per cent)					
		Clear day in			Cloudy day in		
		Spring	Summer	Winter	Summer	Autumn	Winter
2	SW	2·68	2·18	5·2	1·21	4·55	5·2
3	SW	2·17	2·17	6·4	0·87	8·15	5·9
4	SW	4·31	3·42	5·7	1·21	1·93	4·[illegible]
5	SW	2·72	1·40	1·4	1·54	2·10	1·0
6	SW	4·09	2·71	7·8	0·9	2·31	4·2
8	SW	1·71	2·17	2·4	0·9	0·19	2.1
9	SW	2·66	0·56	4·1	2·17	0·97	2·7
10-11	SW	1·37	1·21	1·7	1·35	2·17	0·7
R-A	SW	0·87	1·02	0·8	1·22	1·19	2·6
51	SW	2·38	..	..	0·97	5·75	3·2
45	NE	2·42	1·51	2·5	0·87	2·06	..
46	NE	1·34	0·69	..	0·97	4·88	3·1
48	NE	1·51	1·71	..	0·86	2·48	3·1
12	NW	2·40	1·25	1·5	0·97	0·67	1·6
13	NW	2·72	2·74	2·8	1·93	2·83	2·8
14	NW	2·67	1·55	1·4	1·56	0·97	1·2
22	NW	1·57	1·74	2·9	1·11	1·74	3·4
23	NW	1·09	1·57	0·8	0·61	0·76	0·7
24*	NW	2·42	1·75	..	1·54	.	..
26	SE	1·19	0·88	0·9	0·97	1·94	0·8
27	SE	1·89	1·94	1·7	1·76	2·33	1·4
29	SE	2·18	2·18	3·4	1·25	2·72	2·6
30	SE	3·88	1·21	2.1	1·11	1·74	1·8
53	S	1·67	1·11	..	1·01	6·53	..
54	S	2·72	1·08	..	1·21	3·80	5·2
41	N	1·51	1·93	3·5	1·11	2·75	..
43	N	2·16	1·49	10·1	1·21	3·53	8·8
44	N	2·42	1·19	5·1	1·56	3·57	7·0
65-66	N	2·97	1·39	4·3	1·74	2·76	3·7
33	E	4·19	3·08	4·5	1·09	1·41	4·1
34	E	5·50	2·72	9·6	1·40	2·51	6·4
35	E	2·72	3·74	4·5	0·84	2·74	.
36	E	1·74	5·54	3·1	1·11	2·36	2·4
37	E	2·98	2·11	3·7	1·11	2.91	2·9
38	E	1·71	2·80	1·7	0·97	4·55	1·5
40	E	3·41	3·10	5·3	0·54	1.78	3·9
55	E	2·17	2·24	4·9	1·21	2·14	4·0
57	E	4·35	2·24	1·1	1·27	1·10	1·1
59	E	1·74	0·86	2·1	0·61	1·15	1·5
60	E	1·34	1·21	2·6	0·87	0·97	1·7
42	N	1·94	1·75	2.8	1·21	2·75	2·4

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*(1) Door was kept open during observations.

(2) Winter observations have been taken 33 in. above the Ground and represent the average of observations at five different points in the room.

TABLE XVI
DAMPNESS PENETRATION OBSERVATIONS

(After 6·6″ continuous rain for 28 hours).

House No.	Facing	Roofs	Walls	Joints & Corners	Miscellaneous
2.	SW	None visible.	Badly wet . South wall wet only at almirah.	Window joints damp.	Water comes through ventilation.
3.	SW	Do	Slightly damp Patches visible on East wall.	Window joints damp.	None visible.
4	SW	A Small patch	East wall nearly half damp.	Roof corner leaking inside.	Do
5.	SW	Mildly damp.	...	All roof corners showing wet patches.	Water leaking through window.
6	SW	None visible.	Leaking at expansion joints only.	Patches visible at joints of skylight.	None visible.
8	SW	Do	Do	None visible.	Do
9	SW	Damp.	Do	Do	Do
10-11	SW	None visible.	None visible	Do	Floor is damp.
R-A	SW	Do	Very few visible patches.	Leaking at joints or roof.	None visible.
51.	SW	Damp at middle.	None visible.	Damp at roof joints.	Almirah of east wall damp.
45.	NE	None visible.	East wall only half damp.	None visible.	None visible.
46.	NE	Do	East wall damp all over.	All corners leaking.	Do
48.	NE	Only at joints of slabs.	East wall completely damp except at ston-lined portion.	None visible.	Do
12.	NW	Single patch at corners.	A few damp patches only.	Do	Rain water comes through the door at floor level.
13.	NW	None visible.	East wall wet	Only one roof corner at east is wet.	None visible.
14.	NW	Do	North-East wall wet	None visible.	Do
22.	NW	Roof dripping.	Wet walls.	Do	Do
23.	NW	Do	Do	All roof corners leaking.	Do
24.	NW	Damp through louvres of the doors.	Extremely wet	None visible.	Do
26.	SE	Damp.	Damp.	Damp.	Do
27.	SE	None visible.	Damp outside and inside.	None visible.	None visible.
29.	SE	Do	Damp	Do	Do
30.	SE	Do	50% North East wall damp.	Do	Do
53.	S	A bit damp.	Very damp.	Badly damp.	Water trickling through windows.
54.	S	Leaking.	Profusely damp.	Do	None visible.
41.	N	Few patches	East wall quits damp all over.	Damp at roof joints.	Do

TABLE XVI—DAMPNESS PENETRATION OBSERVATIONS. (*Contd.*)

(After 6·6″ continuous rain for 28 hours)

House No.	Facing	Roofs	Walls	Joints & Corners	Miscellaneous
42. .	N	None visible	A single patch only.	None visible	None visible.
43. .	N	Dripping from roofs	All walls wet	All roof joints and corners leaking	Do
44. .	N	None visible	Only small patches.	None visible	Do
65-66 .	N	Do	None visible	Do	Do
33. .	E	Badly damp all over.	Badly damp all over.	Do	Do
34. .	E	Dripping of tin roofs due to bad joints	East wall has damp patches.	Do	Do
35. .	E	None visible	None visible	None visible	No visible patch but a little dampness.
36. .	E	Do	Do	Do	Do
37. .	E	Quite a few patches.	Damp all over	Roof corners leaking.	None visible
38. .	E	None visible	Dampness only at almirah.	Window joints leaking.	Do
40. .	E	Mild patches not visible	Mild patches not visible	Water through window	Do
56. .	E	All wet	All wet	Joints leaking very badly.	Drops visible on wall.
57. .	E	Very few small patches.	Badly damp	Windows joints and roof joints on each side leaking.	None visible
59. .	E	None visible	None visible	None visible	None visible
60. .		Do	Do	Do	Do

TABLE XVIII

Thermal Performance of Buildings with Different Ceiling Heights.

A—Observations at Roorkee.

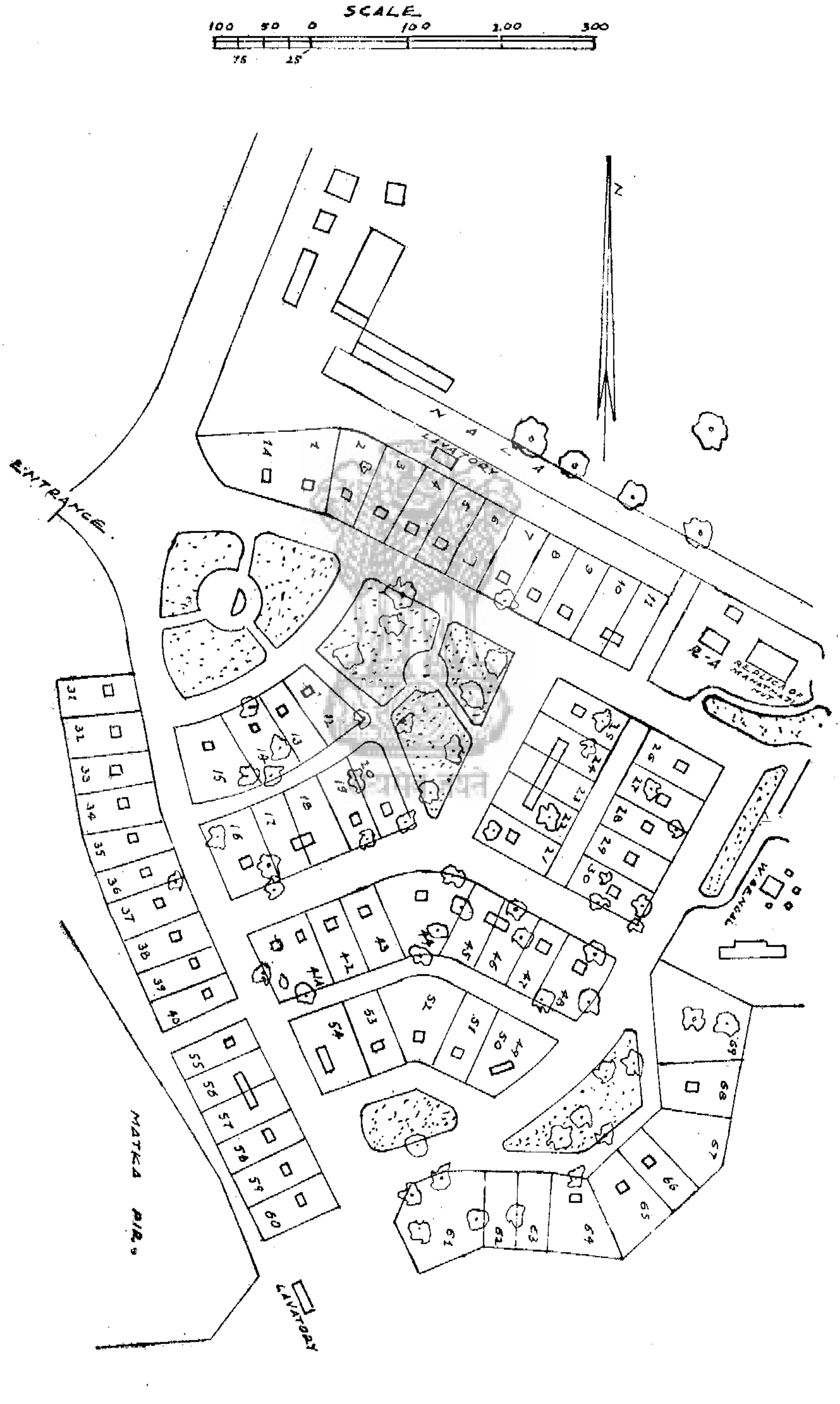
(Ventilation Nil 24 hours with Celotax on glass panes)

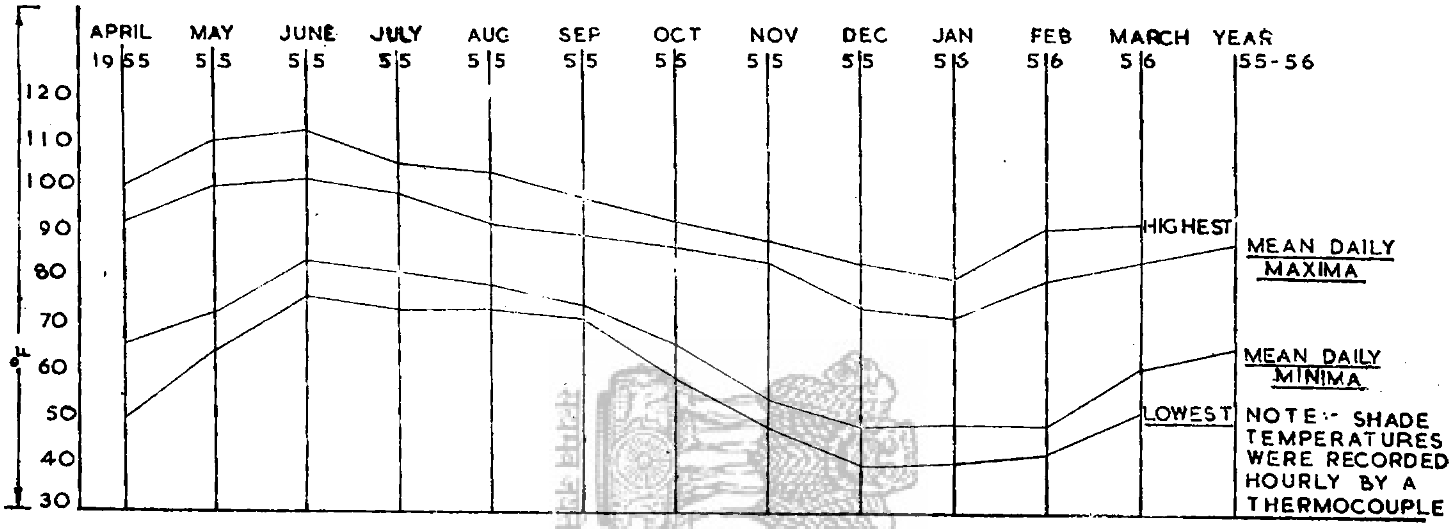
		Thermal Damping (per cent)		Depression in Max. (°F)		Time Lag of Max. Temperature (Hrs)	
		April	May	April	May	April	May
House No.	Ceiling Ht (ft)	1956	1956	1956	1956	1956	1956
Shade	Temp.	99·4	103·4	99·4	103·4	99·4	103·4
1 . .	7½	63	65		2	4	4·5
2 . .	9	62	63		2	4	4·5
3 . .	10½	67	68		2	5	4·5
4 . .	12	66	67		2	4	4·5

B—Observations at Delhi.

Sl. No.	Conditions of Exposure	Ceiling Height (ft)	Thermal Damping (per cent)	Depression in Maximum (°F)	Time lag of Maximum Tem. (Hours)
1	Windows closed with celotex 24 hrs.	11	77	4·5	8
	Ventilators same as windows . .	10	82	5	8
	Fan off. 24 hours	9	84	5	8
	Out door shade Temp 90±8°F .	8	78	3·5	7·5
2	Windows open at night and closed during day	11	67	2	3
	Ventilators same as windows . .	10	78	2	3
	Fan on between 0900 to 1700 hrs. .	9	85	2	2·5
	Out door shade Temp. 83±6°F .	8	59	2·5	2·5
3	Windows open at night and closed during day	11	66	6	2·5
	Ventilators open 24 hours . .	10	75	6	2·5
	Fan off. 24 hours	9	74	6·5	3·0
	Out door shade Temp. 91±9°F .	8	49	5	1·0

FIG : I SITE PLAN OF HOUSES.





NOTE:- SHADE TEMPERATURES WERE RECORDED HOURLY BY A THERMOCOUPLE

FIG. II :- AVERAGE SHADE TEMPERATURES.
AT THE
PROJECT SITE NEW DELHI.

C . B . R . I
COMFORT SURVEY PROJECT
CHECKED BY:-
DRAWN BY:-
TRACED BY:-

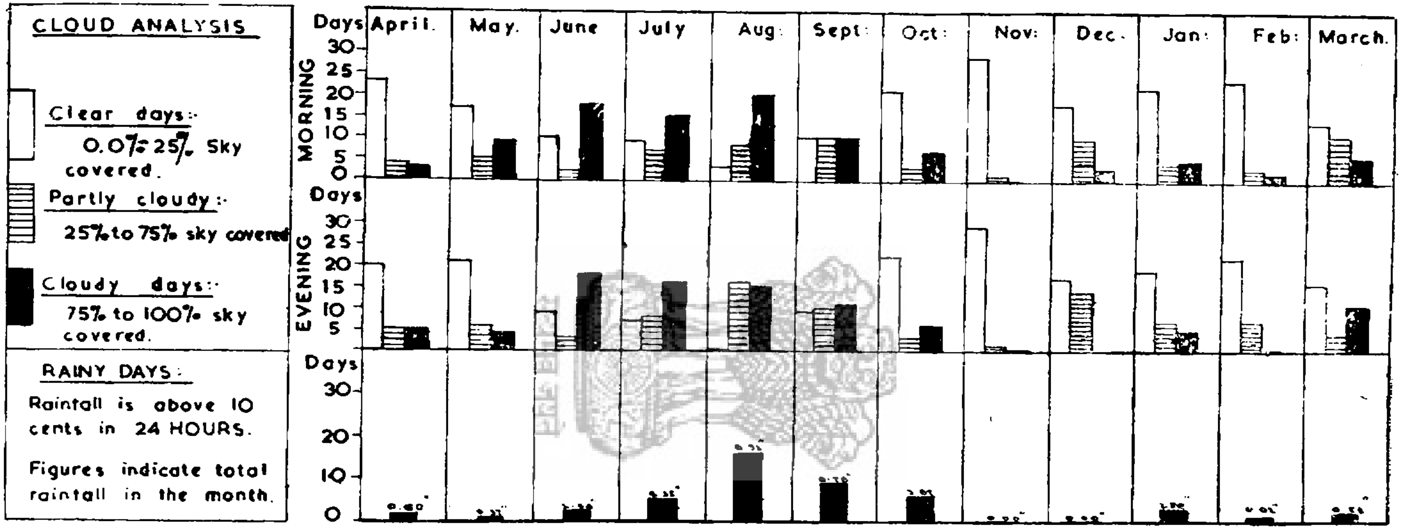


FIG: III. RAIN & CLOUD ANALYSIS

FOR

PROJECT SITE, NEW — DELHI

April, 1955 — March, 1956

C. B. R. I.

COMFORT SURVEY PROJECT

CHECKED BY :-

DRAWN BY :-

TRACED BY :-

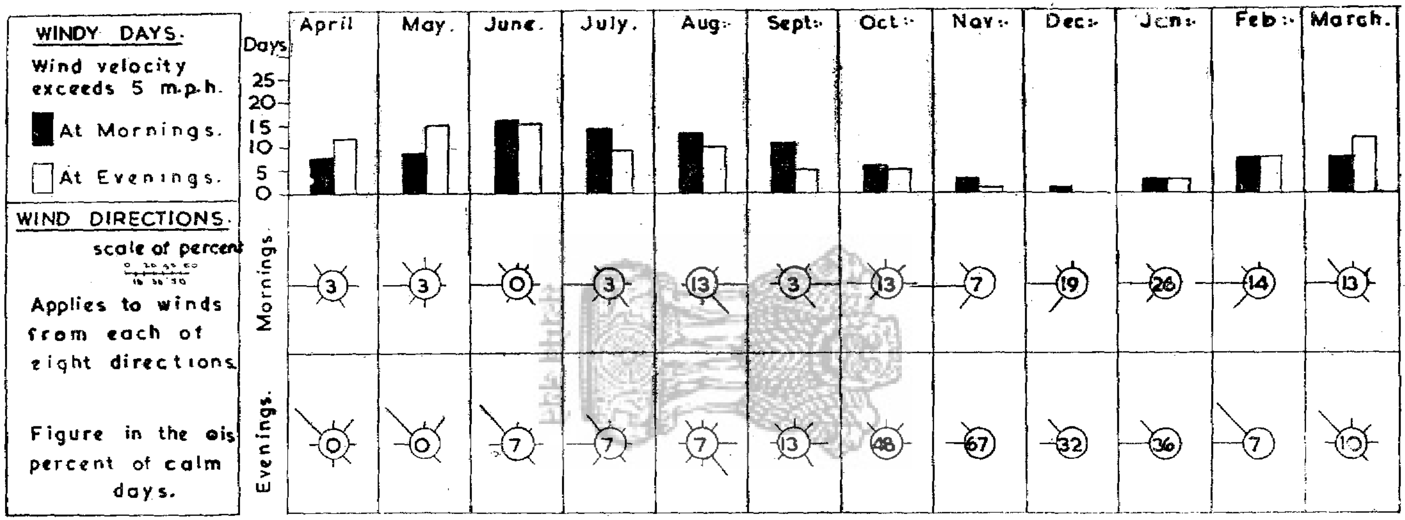
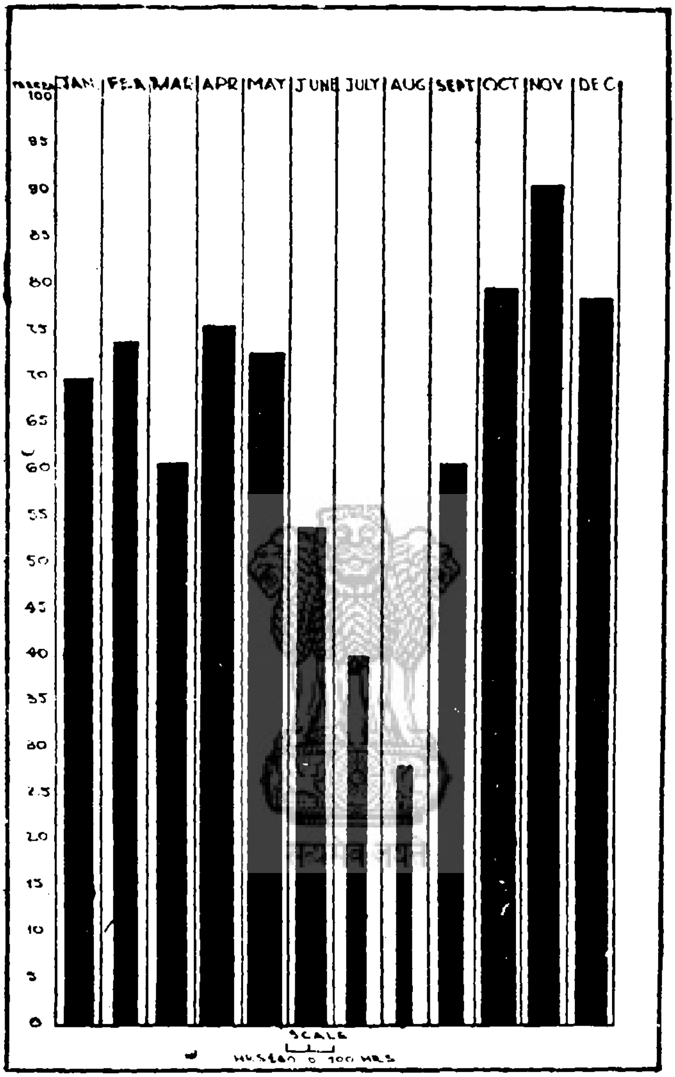


FIG IV. WIND ANALYSIS.
FOR
PROJECT SITE NEW DELHI.
APRIL 1955 - MARCH 1956.

C. B. R. I.
COMFORT SURVEY PROJECT.
CHECKED BY :-
DRAWN BY :-
TRACED BY :-

FIG:- V. HOURS OF SUNSHINE



NOTE :- 1 THIS DIAGRAM IS BASED ON THE DATA OF NORMALS FOR NEW DELHI TAKEN FROM INDIA METEOROLOGICAL DEPARTMENT RECORDS

2 PERCENTAGE REPRESENTS $\frac{\text{ACTUAL HOURS OF SUNSHINE}}{\text{POSSIBLE HOURS OF SUNSHINE}} \times 100$

3 THICKNESS OF ORDINATE IS PROPORTIONAL TO HOURS (ACTUAL) OF SUNSHINE

C.B.R.I.
COMFORT SURVEY PROJECT
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DRAWN BY:
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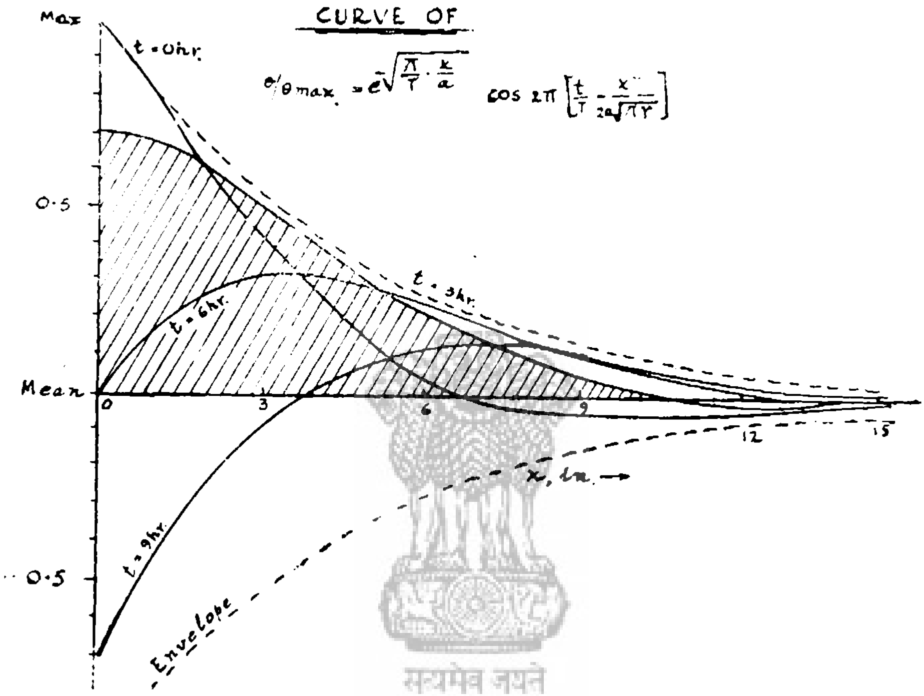

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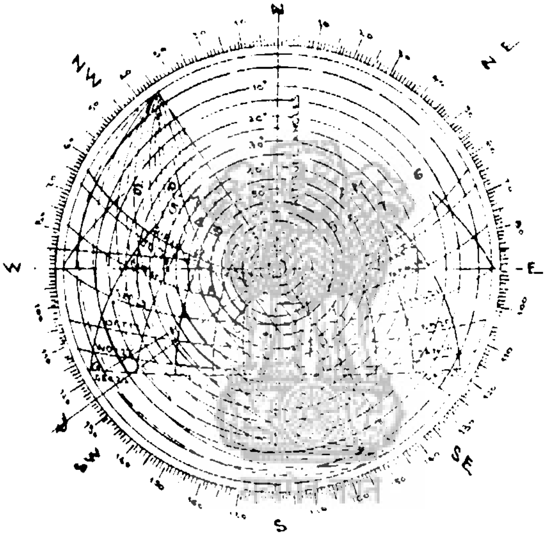
FIG. VI HEAT PENETRATION THROUGH MASONRY.

FIG VI. SOLAR CHART FOR DELHI REGION
(ILLUSTRATING THE SHADOW ANGLE
PROTRACTOR PLACED OVER CHART)



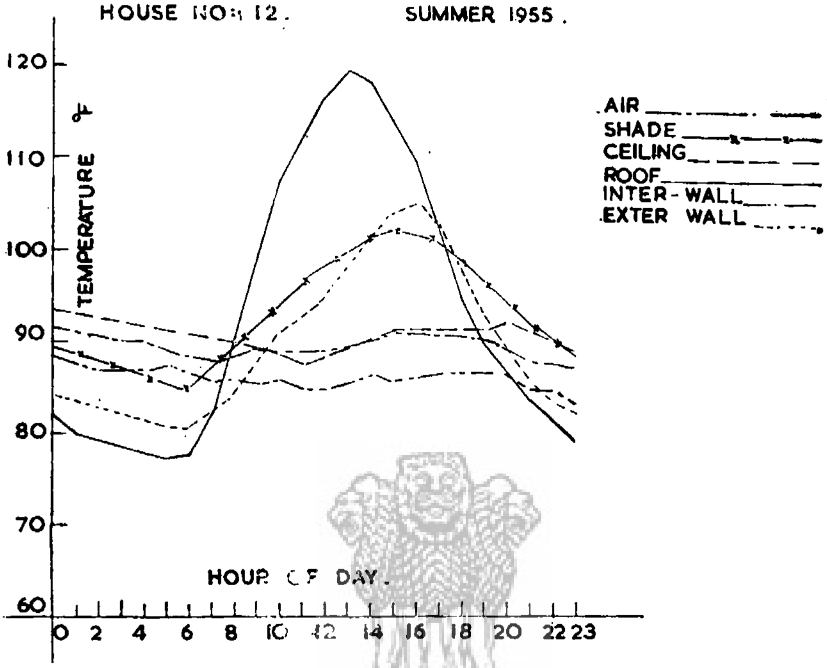
TAKEN FROM THE BULLETIN OF THE
NATIONAL INSTITUTE OF SCIENCES OF INDIA
NO 9, 1955

NOTE · N REPRESENTS TRUE NORTH
TIMES INDICATED ARE THE SOLAR TIMES.

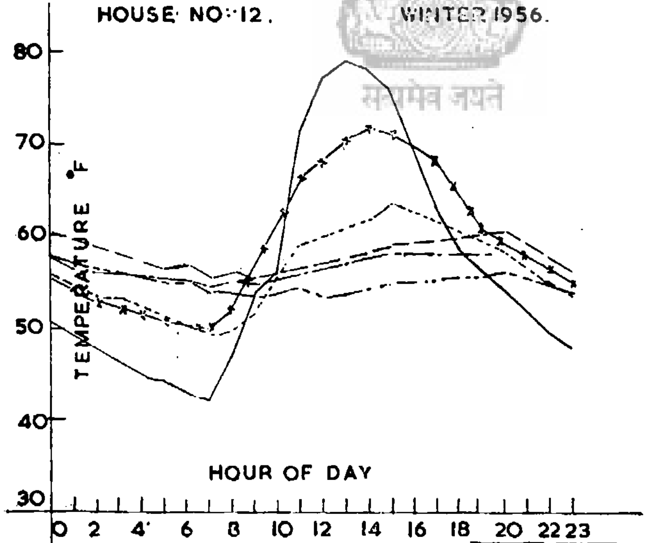
CHECKED BY ..
TRACED BY SUDARSHAN

FIG : VIII. TEMPERATURE CURVES FOR UNVENTILATED HOUSE.

HOUSE NO: 12. SUMMER 1955.



HOUSE NO: 12. WINTER 1956.



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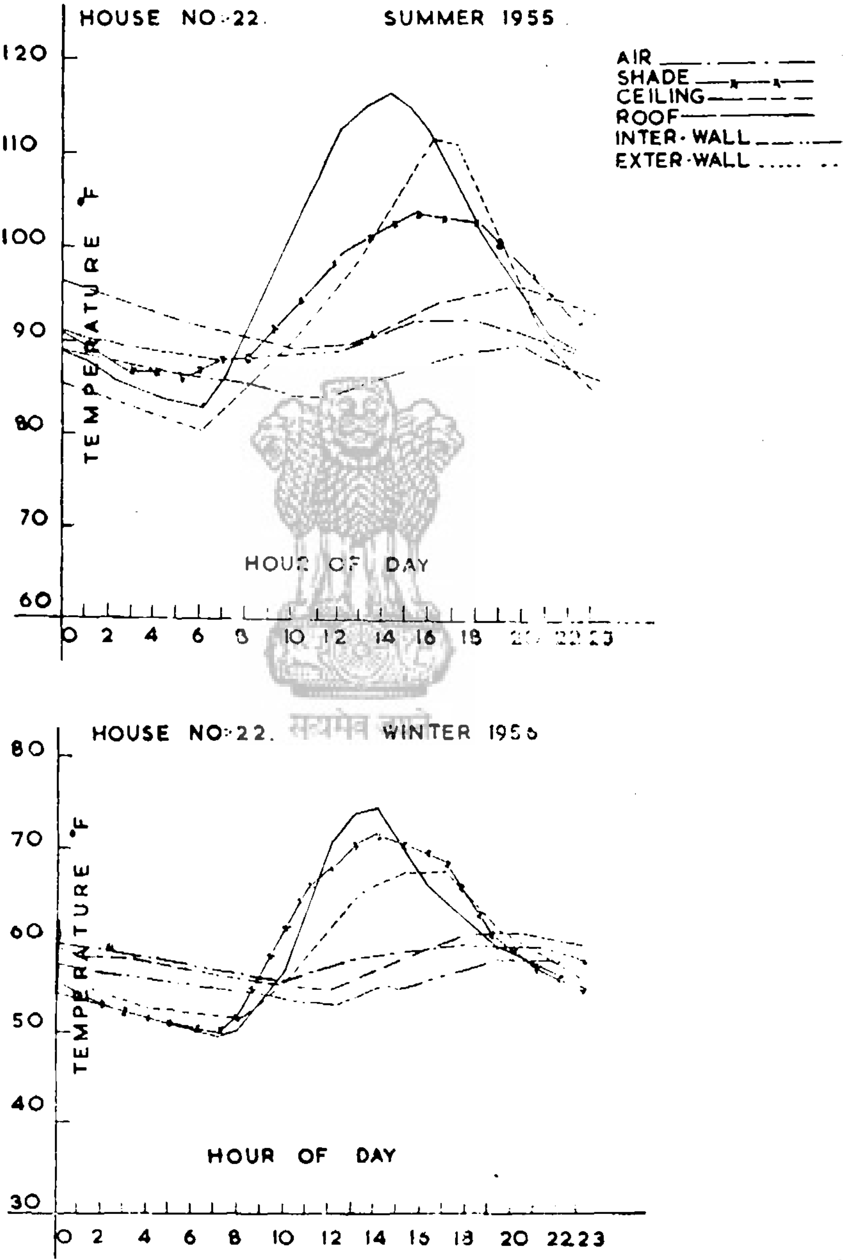
COMFORT SURVEY PROJECT.
CHECKED BY :-
DRAWN BY :-
TRACED BY :-

FIG :- IX . TEMPERATURE CURVES FOR UNVENTILATED HOUSE .



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COMFORT SURVEY PROJECT.
CHECKED BY :-
DRAWN BY :-
TRACED BY :-

FIG:X. THERMAL BEHAVIOUR CHART

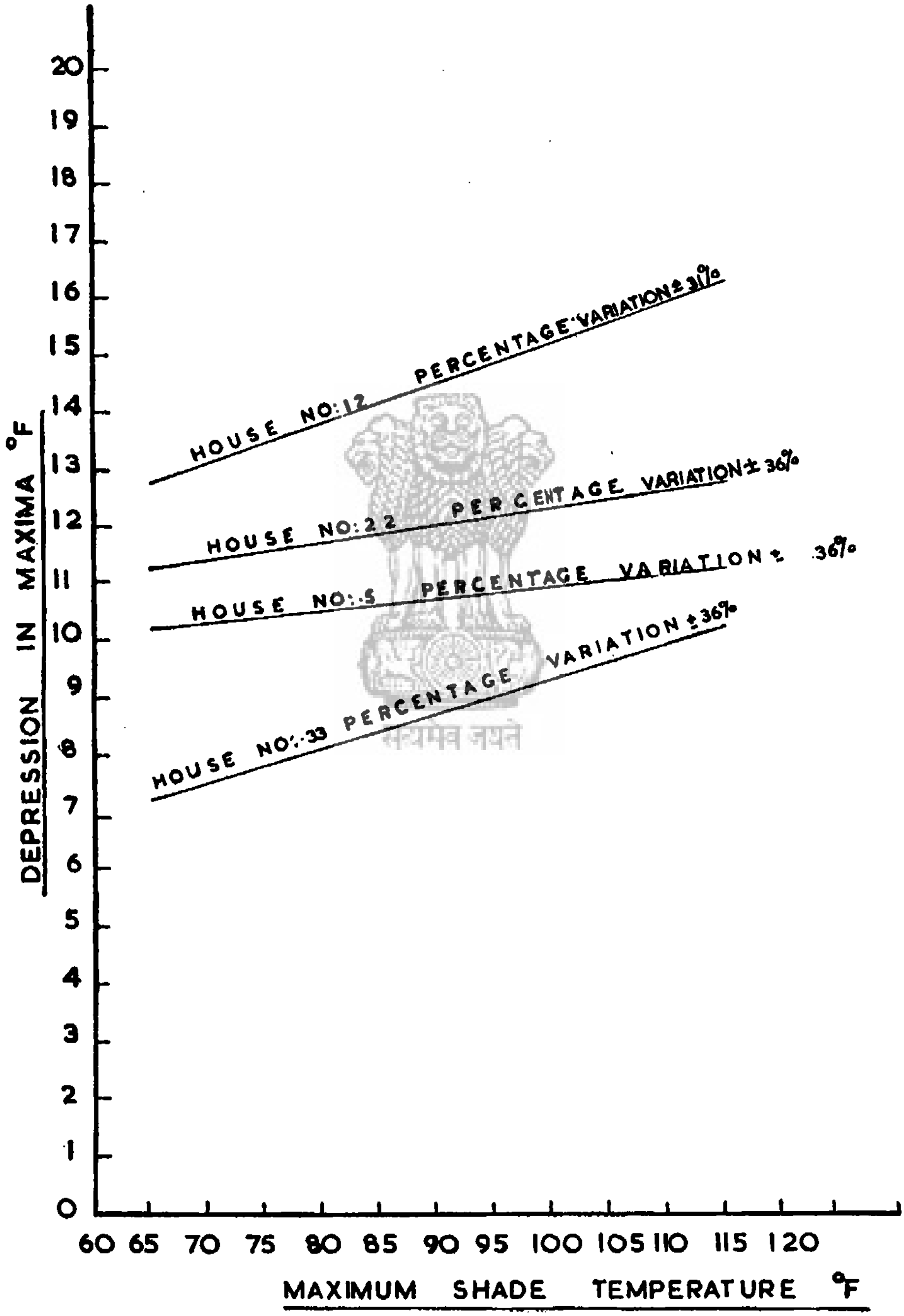

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FIG: XI, RATES OF COOLING.

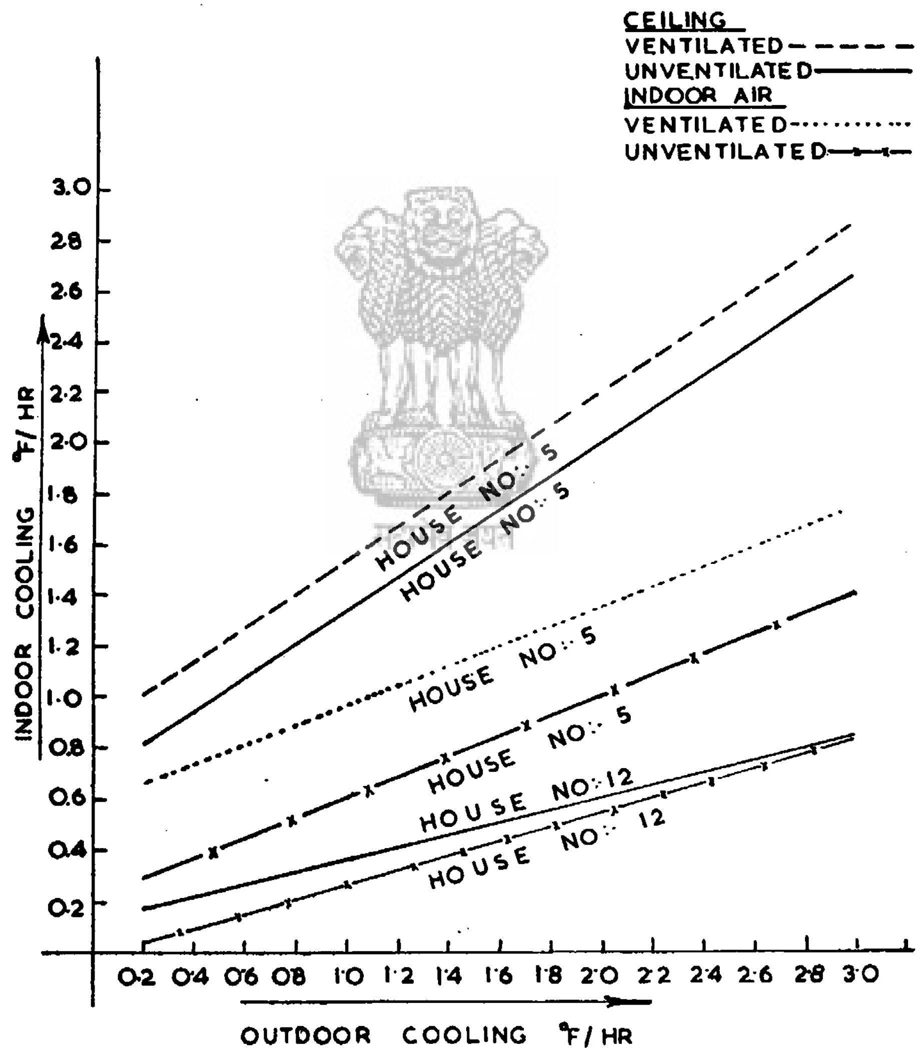


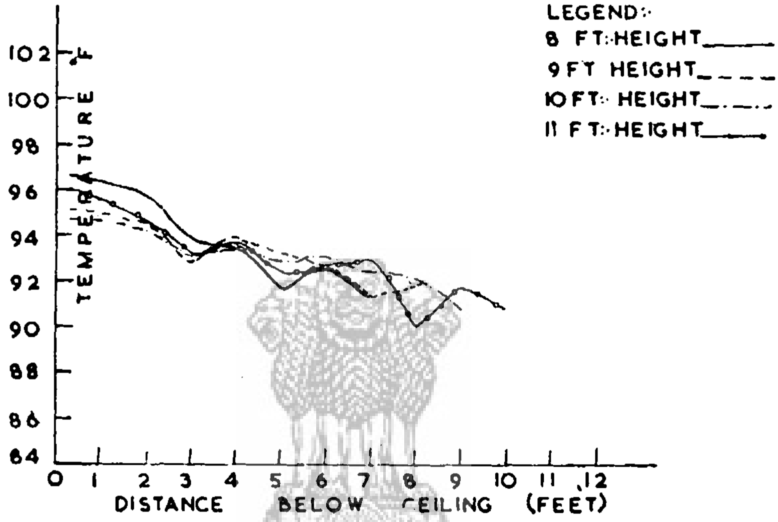
FIG: XII, TEMPERATURE GRADIENT OF MAXIMA

UNVENTILATED HOUSES (NEW DELHI).

(SHADE TEMPERATURE = 90±8°F)

JULY, 1956.

TEMPERATURE CURVES



REGRESSION LINES.

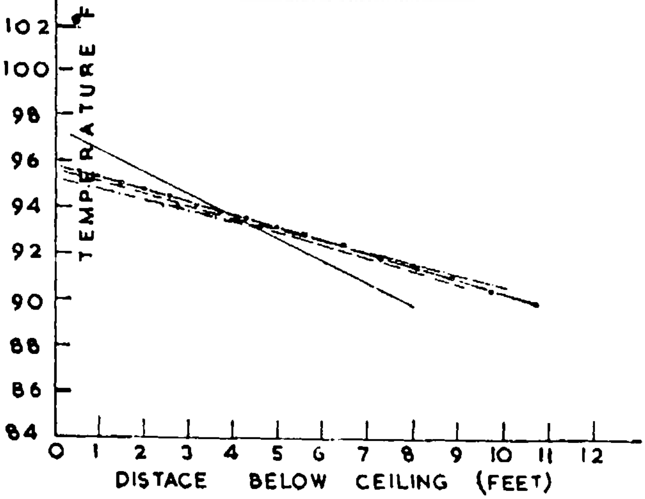


FIG : XIII. TEMPERATURE GRADIENT OF MAXIMA
UNVENTILATED HOUSES (ROORKEE).
(SHADE TEMPERATURE = 77.6 ± 8.0°F)
SEPTEMBER, 1956.

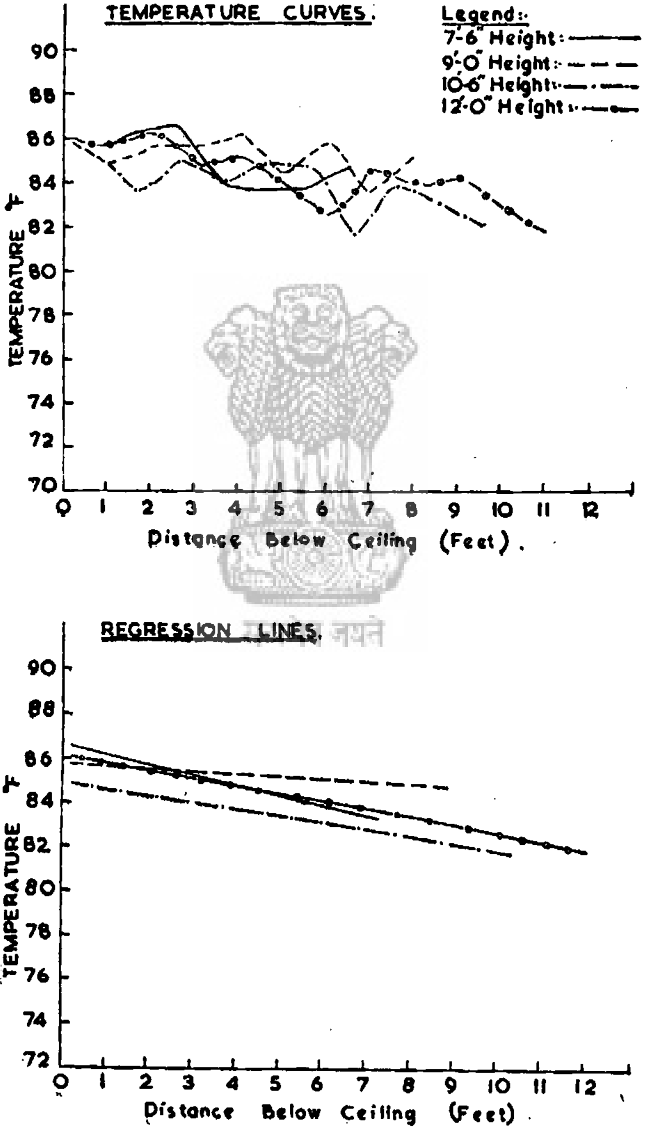
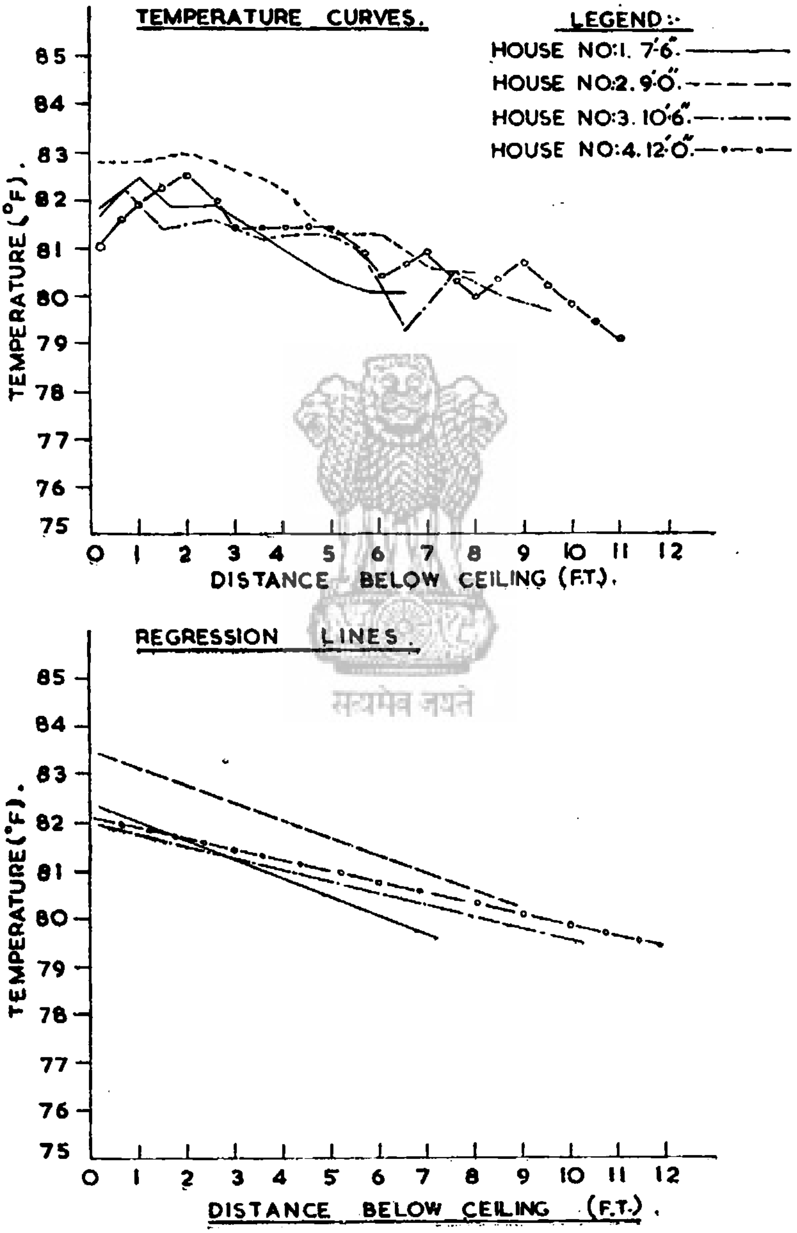


FIG: XIV. TEMPERATURE GRADIENT AT 4. P.M.

(UNVENTILATED HOUSES — ROORKEE.)

(SHADE TEMPERATURE : 73.0±78°F)

OCTOBER, 1956.



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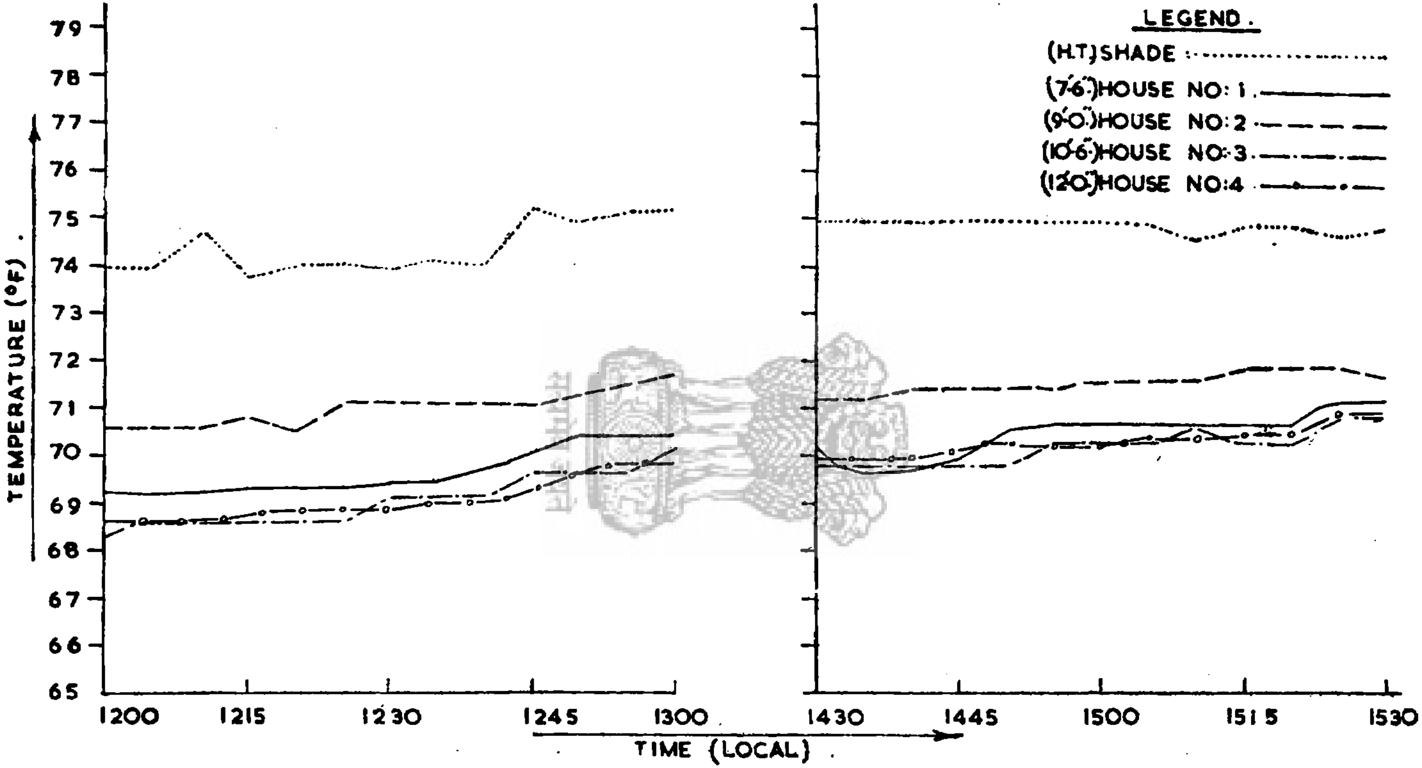

FIG: XV. RISE OF TEMPERATURE IN OCCUPIED ROOMS.

(UNVENTILATED HOUSES - ONE PERSON INSIDE.)
(SUNNY DAYS - WIND 4 M.P.H.)
NOVEMBER, 1956.

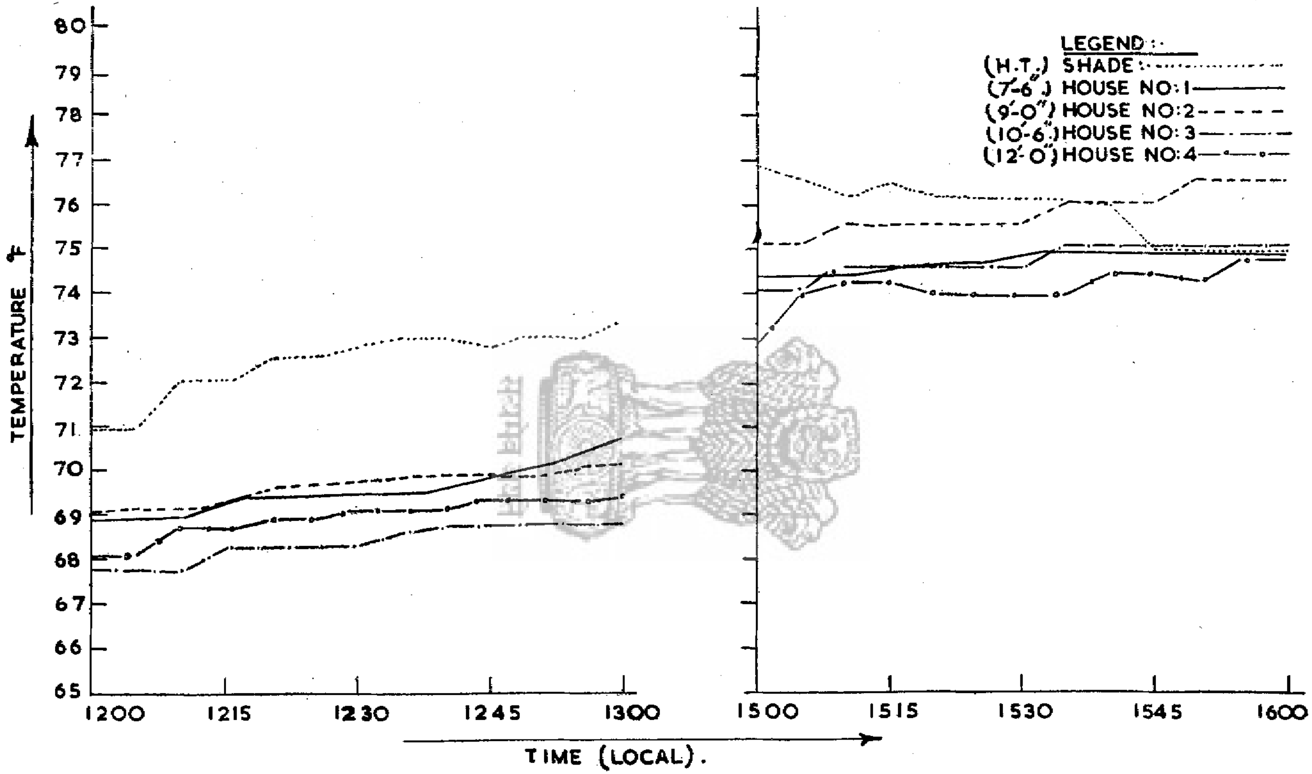

FIG:-XVI, RISE OF TEMPERATURE IN OCCUPIED ROOMS.

(HOUSES UNVENTILATED-4 PERSONS INSIDE.)
(SUNNY DAYS — AVERAGE WIND 5 M.P.H.)
NOVEMBER, 1956.

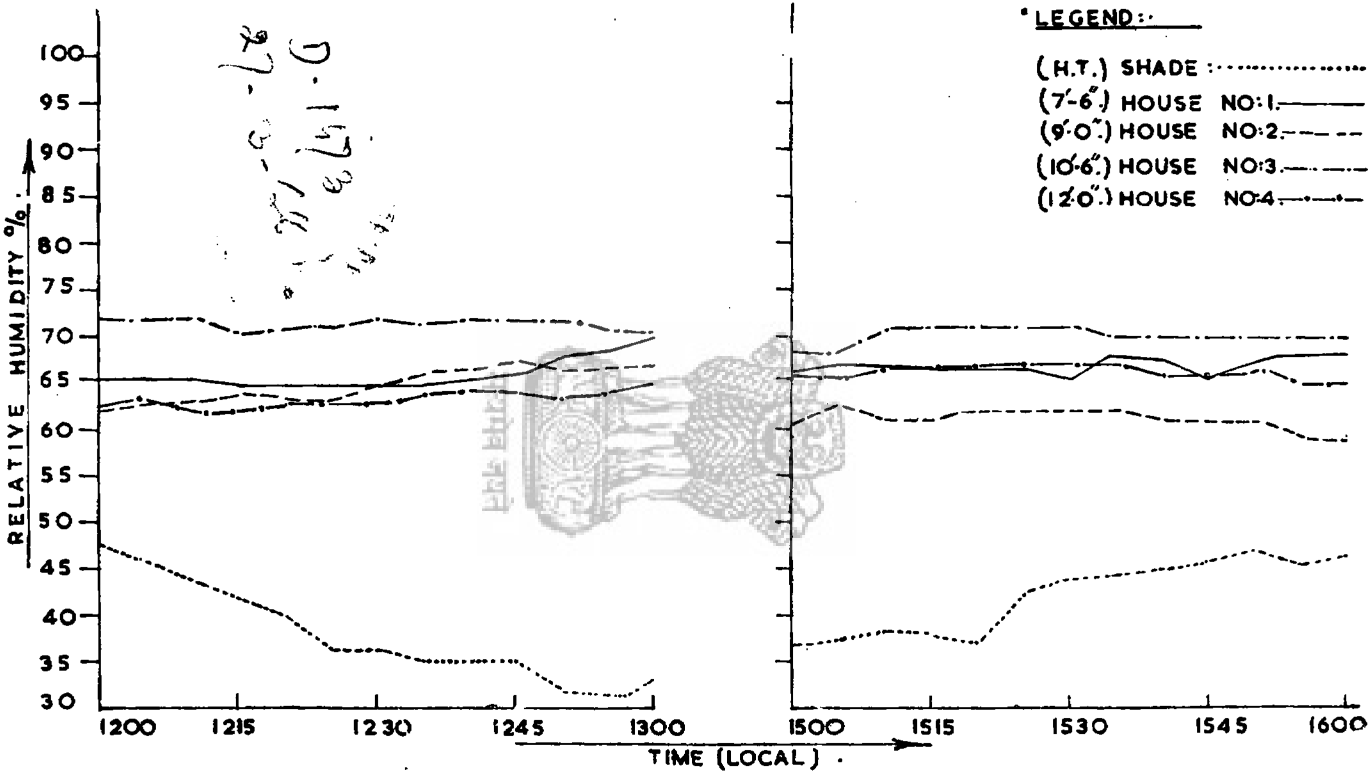

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FIG: XVII. RISE OF HUMIDITY IN OCCUPIED ROOMS.

(HOUSES UNVENTILATED-4 PERSONS INSIDE.)
(SUNNY DAYS—AVERAGE WIND 5 M. P. H.)
NOVEMBER, 1956.

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